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Authorship and citation manipulation in academic research

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Abstract

Some scholars add authors to their research papers or grant proposals even when those individuals contribute nothing to the research effort. Some journal editors coerce authors to add citations that are not pertinent to their work and some authors pad their reference lists with superfluous citations. How prevalent are these types of manipulation, why do scholars stoop to such practices, and who among us is most susceptible to such ethical lapses? This study builds a framework around how intense competition for limited journal space and research funding can encourage manipulation and then uses that framework to develop hypotheses about who manipulates and why they do so. We test those hypotheses using data from over 12,000 responses to a series of surveys sent to more than 110,000 scholars from eighteen different disciplines spread across science, engineering, social science, business, and health care. We find widespread misattribution in publications and in research proposals with significant variation by academic rank, discipline, sex, publication history, co-authors, etc. Even though the majority of scholars disapprove of such tactics, many feel pressured to make such additions while others suggest that it is just the way the game is played. The findings suggest that certain changes in the review process might help to stem this ethical decline, but progress could be slow.

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Introduction

The pressure to publish and to obtain grant funding continues to build [1–3]. In a recent survey of scholars, the number of publications was identified as the single most influential component of their performance review while the journal impact factor of their publications and order of authorship came in second and third, respectively [3]. Simultaneously, rejection rates are on the rise [4]. This combination, the pressure to increase publications coupled with the increased difficulty of publishing, can motivate academics to violate research norms [5]. Similar struggles have been identified in some disciplines in the competition for research funding [6]. For journals and the editors and publishers of those journals, impact factors have become a mark of prestige and are used by academics to determine where to submit their work, who

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earns tenure, and who may be awarded grants [7]. Thus, the pressure to increase a journal's impact factor score is also increasing. With these incentives it is not surprising that academia is seeing authors and editors engaged in questionable behaviors in an attempt to increase their publication success.

There are many forms of academic misconduct that can increase an author's chance for publication and some of the most severe cases include falsifying data, falsifying results, opportunistically interpreting statistics, and fake peer-review [5, 8–12]. For the most part, these extreme examples seem to be relatively uncommon; for example, only 1.97% of surveyed academics admit to falsifying data, although this probably understates the actual practice as these respondents report higher numbers of their colleagues misbehaving [10].

Misbehavior regarding attribution, on the other hand, seems to be widespread [13–18]; for example, in one academic study, roughly 20% of survey respondents have experienced coercive citation (when editors direct authors to add citations to articles from the editors' journals even though there is no indicated lack of attribution and no specific articles or topics are suggested by the editor) and over 50% said they would add superfluous citations to a paper being submitted to a coercive journal in an attempt to increase its chance for publication [18]. Honorary authorship (the addition of individuals to manuscripts as authors, even though those individuals contribute little, if anything, to the actual research) is a common behavior in several disciplines [16, 17]. Some scholars pad their references in an attempt to influence journal referees or grant reviewers by citing prestigious publications or articles from the editor's journal (or the editor's vita) even if those citations are not pertinent to the research. While there is little systematic evidence that such a strategy influences editors, the perception of its effectiveness is enough to persuade some scholars to pad [19, 20]. Overall, it seems that many scholars consider authorship and citation to be fungible attributes, components of a project one can alter to improve their publication and funding record or to increase journal impact factors (JIFs).

Most studies examining attribution manipulation focus on the existence and extent of misconduct and typically address a narrow section of the academic universe; for example, there are numerous studies measuring the amount of honorary authorship in medicine, but few in engineering, business, or the social sciences [21–25]. And, while coercive citation has been exposed in the some business fields, less is known about its prevalence in medicine, science, or engineering. In addition, the pressure to acquire research funding is nearly as intense as publication pressures and in some disciplines funding is a major component of performance reviews. Thus, grant proposals are also viable targets of manipulation, but research into that behavior is sparse [2, 6]. However, if grant distributions are swayed by manipulation then resources are misdirected and promising areas of research could be neglected.

There is little disagreement with the sentiment that this manipulation is unethical, but there is less agreement about how to slow its use. Ultimately, to reverse this decline of ethics we need to better understand the factors that impact attribution manipulation and that is the focus of this manuscript. Using more than 12,000 responses to surveys sent to more than 110,000 academics from disciplines across the academic universe, this study aims to examine the prevalence and systematic nature of honorary authorship, coercive citation, and padded citations in eighteen different disciplines in science, engineering, medicine, business, and the social sciences. In essence, we do not just want to know how common these behaviors are, but whether there are certain types of academics who add authors or citations or are coerced more often than others. Specifically, we ask, what are the prevailing attributes of scholars who manipulate, whether willingly (e.g., padded citation) or not (e.g., coercive citation), and we consider attributes like academic rank, gender, discipline, level of co-authorship, etc. We also look into the reasons scholars manipulate and ask their opinions on the ethics of this behavior. In our opinion, a deeper understanding of manipulation can shed light on potential ways to reduce this type of academic misconduct.

Background

As noted in the introduction, the primary component of performance reviews, and thus of individual research productivity, is the number of published articles by an academic [3]. This number depends on two things: (i) the number of manuscripts on which a scholar is listed as an author and (ii) the likelihood that each of those manuscripts will be published. The pressure to increase publications puts pressure on both of these components. In a general sense, this can be beneficial for society as it creates incentives for individuals to work harder (to increase the quantity of research projects) and to work better (to increase the quality of those projects) [6]. There are similar pressures and incentives in the application for, and distribution of, research grants as many disciplines in science, engineering, and medicine view the acquisition of funding as both a performance measure and a precursor to publication given the high expense of the equipment and supplies needed to conduct research [2, 6]. But this publication and funding pressure can also create perverse incentives.

Honorary authorship

Working harder is not the only means of increasing an academic's number of publications. An alternative approach is known as "honorary authorship" and it specifically refers to the inclusion of individuals as authors on manuscripts, or grant proposals, even though they did not contribute to the research effort. Numerous studies have explored the extent of honorary authorship in a variety of disciplines [17, 20, 21–25]. The motivation to add authors can come from many sources; for instance, an author may be directed to add an individual who is a department chair, lab director, or some other administrator with power, or they might voluntarily add such an individual to curry favor. Additionally, an author might create a reciprocal relationship where they add an honorary author to their own paper with the understanding that the beneficiary will return the favor on another paper in the future, or an author may just do a friend a favor and include their name on a manuscript [23, 24]. In addition, if the added author has a prestigious reputation, this can also increase the chances of the manuscript receiving a favorable review. Through these means, individuals can raise the expected value of their measured research productivity (publications) even though their actual intellectual output is unchanged.

Similar incentives apply to grant funding. Scholars who have a history of repeated funding, especially funding from the more prestigious funding agencies, are viewed favorably by their institutions [2]. Of course, grants provide resources, which increase an academic's research output, but there are also direct benefits from funded research accruing to the university: overhead charges, equipment purchases that can be used for future projects, graduate student support, etc. Consequentially, "rainmakers" (scholars with a record of acquiring significant levels of research funding) are valued for that skill.

As with publications, the amount of research funding received by an individual depends on the number and size of proposals put forth and the probability of each getting funded. This metric creates incentives for individuals to get their names on more proposals, on bigger proposals, and to increase the likelihood that those proposals will be successful. That pressure opens the door to the same sorts of misattribution behavior found in manuscripts because honorary authorship can increase the number of grant proposals that include an author's name and by adding a scholar with a prestigious reputation as an author they may increase their chances of being funded. As we investigate the use of honorary authorship we do not focus solely on its prevalence; we also question whether there is a systematic nature to its use. First, for example, it makes sense that academics who are early in their career have less funding and lack the protection of tenure and thus need more publications than someone with an established reputation. To begin to understand if systematic differences exist in the use of honorary authorship, the first set of empirical questions to be investigated here is: who is likely to add honorary authors to manuscripts or grant proposals? Scholars of lower rank and without tenure may be more likely to add authors, whether under pressure from senior colleagues or in their own attempt to sway reviewers. Tenure and promotion depend critically on a young scholars' ability to establish a publication record, secure research funding, and engender support from their senior faculty. Because they lack the protection of rank and tenure, refusing to add someone could be risky. Of course, senior faculty members also have goals and aspirations that can be challenging, but junior faculty have far more on the line in terms of their career.

Second, we expect research faculty to be more likely to add honorary authors, especially to grant proposals, because they often occupy positions that are heavily dependent on a continued stream of research success, particularly regarding research funding. Third, we expect that female researchers may be less able to resist pressure to add honorary authors because women are underrepresented in faculty leadership and administrative positions in academia and lack political power [26, 27]. It is not just their own lack of position that matters; the dearth of other females as senior faculty or in leadership positions leave women with fewer mentors, senior colleagues, and administrators with similar experiences to help them navigate these political minefields [28, 29]. Fourth, because adding an author waters down the credit received by each existing author, we expect manuscripts that already have several authors to be less resistant to additional "credit sharing." Simply put, if credit is equally distributed across authors then adding a second author would cut your perceived contribution in half, but adding a sixth author reduces your contribution by only 3% (from 20% to 17%).

Fifth, because academia is so competitive, the decisions of some scholars have an impact on others in the same research population. If your research interests are in an area in which honorary authorship is common and considered to be effective, then a promising counter-policy to the manipulation undertaken by others is to practice honorary authorship yourself. This leads us to predict that the obligation to add honorary authors to grant proposals and/or manuscripts is likely to concentrate more heavily in some disciplines. In other words, we do not expect it to be practiced uniformly or randomly across fields; instead, there will be some disciplines who are heavily engaged in adding authors and other disciplines less so engaged. In general, we have no firm predictions as to which disciplines are more likely to practice honorary authorship; we predict only that its practice will be lumpy. However, there may be reasons to suspect some patterns to emerge; for example, some disciplines, such as science, engineering, and medicine, are much more heavily dependent on research funding than other disciplines, such as the social sciences, mathematics, and business [2]. For example, over 70% of the NSF budget goes to science and engineering and about 4% to the social sciences. Similarly, most of the NIH budget goes to doctors and a smaller share to other disciplines [30]. Consequently, we suspect that the disciplines that most prominently add false investigators to grant proposals are more likely to be in science, engineering, and the medical fields. We do not expect to see that division as prominent in the addition of authors to manuscripts submitted for publication.

There are several ways scholars may internalize the pressure to perform, which can lead to different reasons why a scholar might add an honorary author to a paper. A second goal of this paper is to study who might employ these different strategies. Thus, we asked authors for the reasons they added honorary authors to their manuscripts and grants; for example, was this person in a position of authority, or a mentor, did they have a reputation that increased the chances for publication or funding, etc? Using these responses as a dependent variable, we then look to find out if these were related to the professional characteristics of the scholars in our study. The hypotheses to be tested mirror the questions posed for honorary authors. We expect junior faculty, research faculty, female faculty, and projects with more co-authors to be more likely to add additional coauthors to manuscripts and grants than professors, male faculty, and projects with fewer co-authors. Moreover, we expect for the practice to differ across disciplines. Focusing specifically on honorary authorship in grant proposals, we also explore the possibility that the use of honorary authorship differs between funding opportunities and agencies.

Coercive citation

Journal rankings matter to editors, editorial boards, and publishers because rankings affect subscriptions and prestige. In spite of their shortcomings, impact factors have become the dominant measure of journal quality. These measures include self-citation, which creates an incentive for editors to direct authors to add citations even if those citations are irrelevant, a practice called "coercive citation" [18, 27]. This behavior has been systematically measured in business and social science disciplines [18]. Additionally, researchers have found that coercion sometimes involves more than one journal; editors have gone as far as organizing "citation cartels" where a small set of editors recommend that authors cite articles from each other's journal [31].

When editors make decisions to coerce, who might they target, who is most likely to be coerced? Assuming editors balance the costs and benefits of their decisions, a parallel set of empirical hypotheses emerge. Returning to the various scholar attributes, we expect editors to target lower-ranked faculty members because they may have a greater incentive to cooperate as additional publications have a direct effect on their future cases for promotion, and for assistant professors on their chances of tenure as well. In addition, because they have less political clout and are less likely to openly complain about coercive treatment, lower ranked faculty members are more likely to acquiesce to the editor's request. We predict that editors are more likely to target female scholars because female scholars hold fewer positions of authority in academia and may lack the institutional support of their male counterparts. We also expect the number of coauthors to play a role, but contrary to our honorary authorship prediction, we predict editors will target manuscripts with fewer authors rather than more authors. The rationale is simple; authors do not like to be coerced and when an editor requires additional citations on a manuscript having many authors then the editor is making a larger number of individuals aware of their coercive behavior, but coercing a sole-authored paper upsets a single individual. Notice that we are hypothesizing the opposite sign in this model than in the honorary authorship model; if *authors* are making a decision to add honorary authors then they prefer to add people to articles that already have many co-authors, but if *editors* are making the decision then they prefer to target manuscripts with few authors to minimize the potential pushback.

As was true in the model of honorary authorship, we expect the practice of coercion to be more prevalent in some disciplines than others. If one editor decides to coerce authors and if that strategy is effective, or is perceived to be effective, then there is increased pressure for other editors in the same discipline to also coerce just to maintain their ranking—if one journal climbs up in the rankings, others, who do nothing, fall. Consequently, coercion begets additional coercion and the practice can spread. But, a journal climbing up in the rankings in one discipline has little impact on other disciplines and thus we expect to find coercion practiced unevenly; prevalent in some disciplines, less so in others. Finally, as a sub-conjecture to this hypothesis, we expect coercive citation to be more prevalent in disciplines for which journal publication is the dominant measure for promotion and tenure; that is, disciplines that rely less heavily on grant funding. This means we expect the practice to be scattered, and lumpy, but we also expect relatively more coercion in the business and social sciences disciplines.

We are also interested in the types of journals that have been reported to coerce and to explore those issues we gather data using the journal as the unit of observation. As above, we expect differences between disciplines and we expect those discipline differences to mirror the discipline differences found in the author-based data set. We also expect a relationship between journal ranking and coercion because the costs and benefits of coercion differ for more or less prestigious journals. Consider the benefits of coercion. The very highest ranked journals have high impact factors; consequently, to rise another position in the rankings requires a significant increase in citations, which would require a lot of coercion. Lower-ranked journals, however, might move up several positions with relatively few coerced citations. Furthermore, consider the cost of coercion. Elite journals possess valuable reputations and risking them by coercing might be foolhardy; journals deep down in the rankings have less at stake. Given this logic, it seems likely that lower ranked journals are more likely to have practiced coercion.

We also look to see if publishers might influence the coercive decision. Journals are owned and published by many different types of organizations; the most common being commercial publishers, academic associations, and universities. *A priori*, commercial publishers, being motivated by profits, are expected to be more interested in subscriptions and sales, so the return to coercion might be higher for that group. On the other hand, the integrity of a journal might be of greater concern to non-profit academic associations and university publishers, but we don't see a compelling reason to suppose that universities or academic associations will behave differently from one another. Finally, we control for some structural difference across journals by including each journal's average number of cites per document and the total number of documents they publish per year.

Padded citations

The third and final type of attribution manipulation explored here is padded reference lists. Because some editors coerce scholars to add citations to boost their journals' impact factor score and because this practice is known by many scholars there is an incentive for scholars to add superfluous citations to their manuscripts prior to submission [18]. Provided there is an incentive for scholars to pad their reference lists in manuscripts, we wondered if grant writers would be willing to pad reference lists in grants in an attempt to influence grant reviewers.

As with honorary authorship, we suspect there may be a systematic element to padding citations. In fact, we expect the behavior of padding citations to parallel the honorary author behavior. Thus we predict that scholars of lower rank and therefore without tenure and female scholars to be more likely to pad citations to assuage an editor or sway grant reviewers. Because the practice also encompasses a feedback loop (one way to compete with scholars who pad their citations is to pad your citations) we expect the practice to proliferate in some disciplines. The number of coauthors is not expected to play a role, but we also expect knowledge of other types of manipulation to be important. That is, we hypothesize that individuals who are aware of coercion, or who have been coerced, are more likely to pad citations. With grants, we similarly expect individuals who add honorary authors to grant proposals to also be likely to pad citations in grant proposals. Essentially, the willingness to misbehave in one area is likely related to misbehavior in other areas.

Methods

The data collection method of choice for this study is survey because to it would be difficult to determine if someone added honorary authors or padded citations prior to submission without asking that individual. As explained below, we distributed surveys in four waves over five years. Each survey, its cover email, and distribution strategy was reviewed and approved by the University of Alabama in Huntsville's Institutional Review Board. Copies of these approvals are available on request. We purposely did not collect data that would allow us to identify individual respondents. We test our hypotheses using these survey data and journal data. Given the complexity of the data collection, both survey and archival journal data, we will begin with discussing our survey data and the variables developed from our survey. We then discuss our journal data and the variables developed there. Over the course of a five-year period and using four waves of survey collection, we sent surveys, via email, to more than 110,000 scholars in total from eighteen different disciplines (medicine, nursing, biology, chemistry, computer science, mathematics, physics, engineering, ecology, accounting, economics, finance, marketing, management, information systems, sociology, psychology, and political science) from universities across the U.S. See Table 1 for details regarding the timing of survey collection. Survey questions and raw counts of the responses to those questions are given in S1 Appendix: Statistical methods, surveys, and additional results. Complete files of all of the data used in our estimates are in the S2, S3 and S4 Appendices.

Table 1. Timing and coverage of surveys.

	Honorary authors: Manuscripts	Honorary Authors:Grant proposals	Padding Citations: Grant Proposals	Padding Citations: Manuscripts	Coercive citations
Medicine	2012	2012	2012	2012	2012
Nursing	2012	2012	2012	2012	2012
Biology	2012	2012	2012	2013	2013
Chemistry	2012	2012	2012	2013	2013
Physics	2012	2012	2012	2013	2013
Mathematics	2012	2012	2012	2013	2013
Computer Science	2012	2012	2012	2013	2013
Engineering	2012	2012	2012	2013	2013
Ecology	2012	2012	2012	2013	2013
Accounting	2014	2014	2014	2010	2010
Finance	2014	2014	2014	2010	2010
Management	2014	2014	2014	2010	2010
Marketing	2014	2014	2014	2010	2010
Information Systems	2014	2014	2014	2010	2010
Economics	2014	2014	2014	2010	2010
Psychology	2012	2012	2012	2010	2010
Sociology	2012	2012	2012	2010	2010
Political Science	2012	2012	2012	2010	2010

Four waves of surveys were sent to these 18 disciplines over a five year period. First wave (shaded orange) focused on coercive citation in business and the social sciences. Some of these data were used in a published study on coercive citation [18]. Second wave (pink) was early in the spring of 2012 and surveyed the health care disciplines. Third wave (green) was distributed in the fall of 2012 and asked about honorary authorship in STEM disciplines and the social sciences. The fourth wave (shaded blue) filled in the rest of the data; collecting honorary authorship data from business and coercive citation data from the sciences.

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Potential survey recipients and their contact information (email addresses) were identified in three different ways. First, we were able to get contact information for management scholars through the Academy Management using the annual meeting catalog. Second, for economics and physicians we used the membership services provided by the American Economic Association and the American Medical Association. Third, for the remaining disciplines we identified the top 200 universities in the United States using *U.S. News and World Report's* "National University Rankings" and hand-collected email addresses by visiting those university websites and copying contact information for individual faculty members from each of the disciplines. We also augmented the physician contact list by visiting the web sites of the medical schools in these top 200 school as well. With each wave of surveys, we sent at least one reminder to participate. The approximately 110,000 surveys yielded about 12,000 responses for an overall response rate of about 10.5%. Response rates by discipline can be found in Table A in S1 Appendix.

Few studies have examined the systematic nature of honorary authorship and padded citation and thus we developed our own survey items to address our hypotheses. Our survey items for coercive citation were taken from prior research on coercion [18]. All survey items and the response alternatives with raw data counts are given in S1 Appendix. The complete data are made available in S2–S4 Appendices.

Our first set of tests relate to honorary authorship in manuscripts and grants and is made up of several dependent variables, each related to the research question being addressed. We begin with the existence of honorary authorship in manuscripts. This dependent variable is composed of the answers to the survey question: "Have YOU felt obligated to add the name of another individual as a coauthor to your manuscript even though that individual's contribution was minimal?" Responses were in the form of yes and no where "yes" was coded as a 1 and "no" coded as a 0. The next dependent variable addresses the frequency of this behavior asking: "In the last five years HOW MANY TIMES have you added or had coauthors added to your manuscripts even though they contributed little to the study?" The final honorary authorship dependent variables deal with the reason for including an honorary author in manuscripts: "Even though this individual added little to this manuscript he (or she) was included as an author. The main reason for this inclusion was:" and the choices regarding this answer were that the honorary author is the director of the lab or facility used in the research, occupies a position of authority and can influence my career, is my mentor, is a colleague I wanted to help out, was included for reciprocity (I was included or expect to be included as a co-author on their work), has data I needed, has a reputation that increases the chances of the work being published, or they had funding we could apply to the research. Responses were coded as 1 for the main reason given (only one reason could be selected as the "main" reason) and 0 otherwise.

Regarding honorary authorship in grant proposals, our first dependent variable addresses its existence: "Have you ever felt obligated to add a scholar's name to a grant proposal even though you knew that individual would not make a significant contribution to the research effort?" Again, responses were in the form of yes and no where "yes" was coded as a 1 and "no" coded as a 0. The remaining dependent variables regarding honorary authorship in grant proposals addresses the reasons for adding honorary authors to proposals: "The main reason you added an individual to this grant proposal even though he (or she) was not expected to make a significant contribution was:" and the provided potential responses were that the honorary author is the director of the lab or facility used in the research, occupies a position of authority and can influence my career, is my mentor, is a colleague I wanted to help out, was included for reciprocity (I was included or expect to be included as a co-author on their work), has data I needed, has a reputation that increases the chances of the work being published, or was a person suggested by the grant reviewers. Responses were coded as 1 for the main reason given (only one reason could be selected as the "main" reason) and 0 otherwise.

Our next major set of dependent variables deal with coercive citation. The first coercive citation dependent variable was measured using the survey question: "Have YOU received a request from an editor to add citations from the editor's journal for reasons that were not based on content?" Responses were in the form of yes (coded as a 1) and no (coded as 0). The next question deals with the frequency: "In the last five years, approximately HOW MANY TIMES have you received a request from the editor to add more citations from the editor's journal for reasons that were not based on content?"

Our final set of dependent variables from our survey data investigates padding citations in manuscripts and grants. The dependent variable that addresses an author's willingness to pad citations for manuscripts comes from the following question: "If I were submitting an article to a journal with a reputation of asking for citations to itself even if those citations are not critical to the content of the article, I would probably add such citations BEFORE SUBMISSION." Answers to this question were in the form of a Likert scale with five potential responses (Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree) where Strongly Disagree was coded as a 1 and Strongly Agree coded as a 5. The dependent variable for padding citations in grant proposals uses responses to the statement: "When developing a grant proposal I tend to skew my citations toward high impact factor journals, even if those citations are of marginal import to my proposal." Answers were in the form of a Likert scale with five potential responses (Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree) where Strongly Disagree was coded as a 1 and Strongly Agree coded as a 5.

To test our research questions, several independent variables were developed. We begin by addressing the independent variables that cut across honorary authorship, coercive citation, and padding citations. The first is academic rank. We asked respondents their current rank: Assistant Professor, Associate Professor, Professor, Research Faculty, Clinical Faculty, and other. Dummy variables were created for each category with Professor being the omitted category in our tests of the hypotheses. The second general independent variable is discipline: Medicine, Nursing, Accounting, Economics, Finance, Information Systems, Management, Marketing, Political Science, Psychology, Sociology, Biology, Chemistry, Computer Science, Ecology, and Engineering. Again, dummy variables were created for each discipline, but instead of omitting a reference category we include all disciplines and then constrain the sum of their coefficients to equal zero. With this approach, the estimated coefficients then tell us how each discipline differs from the average level of honorary authorship, coercive citation, or padded citation across the academic spectrum [32]. We can conveniently identify three categories: (i) disciplines that are significantly more likely to engage in honorary authorship, coercive citation, or padded citation than the average across all disciplines, (ii) disciplines that do not differ significantly from the average level of honorary authorship, coercive citation, or padded citation across all of these disciplines, and (iii) those who are significantly less likely to engage in honorary authorship, coercive citation, or padded citation than the average. We test the potential gender differences with a dummy variable male = 1, females = 0.

Additional independent variables were developed for specific research questions. In our tests of honorary authorship, there is an independent variable addressing the number of co-authors on a respondent's most recent manuscript. If the respondent stated that they have added an honorary author then they were asked "Please focus on the most recent incidence in which an individual was added as a coauthor to one of your manuscripts even though his or her contribution was minimal. Including yourself, how many authors were on this manuscript?" Respondents who had not added an honorary author were asked to report the number of authors on their most recently accepted manuscript. We also include an independent variable regarding funding agencies: "To which agency, organization, or foundation was this proposal directed?" Again, for those who have added authors, we request they focus on the most recent proposal where they used honorary authorship and for those who responded that they have not practiced honorary authorship, we asked where they sent their most recent proposal. Their responses include NSF, HHS, Corporations, Private nonprofit, State funding, Other Federal grants, and Other grants. Regarding coercive citation, we included an independent variable regarding number of co-authors on their most recent coercive experience and thus if a respondent indicated they've been coerced we asked: "Please focus on the most recent incident in which an editor asked you to add citations not based on content. Including yourself, how many authors were on this manuscript?" If a respondent indicated they've never been coerced, we asked them to state the number of authors on their most recently accepted manuscript.

Finally, we included control variables. In our tests, we included the respondent's performance or exposure to these behaviors. For those analyses focusing on manuscripts we used acceptances: "Within the last five years, approximately how many publications, including acceptances, do you have?" The more someone publishes, the more opportunities they have to be coerced, add authors, or add citations; thus, scholars who have published more articles are more likely to have experienced coercion, ceteris paribus. And in our tests of grants we used two performance indicators: 1) "In the last five years approximately how many grant proposals have you submitted for funding?" and 2) "Approximately how much grant money have you received in the last five years? Please write your estimated dollars in box; enter 0 if zero."

We also investigate coercion using a journal-based dataset, Scopus, which contains information on more than 16,000 journals from these 18 disciplines [33]. It includes information on the number of articles published each year, the average number of citations per manuscript, the rank of the journal, disciplines that most frequently publish in the journal, the publisher, and so forth. These data were used to help develop our dependent variable as well as our independent and control variables for the journal analysis. Our raw journal data is provided in S4 Appendix: Journal data.

The dependent variables in our journal analysis measure whether a specific journal was identified as a journal in which coercion occurred, or not, and the frequency of that identification. Survey respondents were asked: "To track the possible spread of this practice we need to know specific journals. Would you please provide the names of journals you know engage in this practice?" Respondents were given a blank space to write in journal names. The majority of our respondents declined to identify journals where coercion has occurred; however, more than 1200 respondents provided journal names and in some instances, respondents provided more than one journal name. Among the population of journals in the Scopus database, 612 of these were identified as journals that have coerced by our survey respondents, some of these journals were identified several times. The first dependent variable is binary, coded as 1 if a journal was identified as a journal that has coerced, and coded as 0 otherwise. The frequency estimates uses the count, how many times they were named, as the dependent variable.

The independent variables measure various journal attributes, the first being discipline. The Scopus database identifies the discipline that most frequently publishes in any given journal, and that information was used to classify journals by discipline. Thus, if physics is the most common discipline to publish in a journal, it was classified as a physics journal. We look to see if there is a publisher effect using the publisher information in Scopus to create four categories: commercial publishers, academic associations, universities, and others (the omitted reference category).

We also control for differing editorial norms across disciplines. First, we include the number of documents published annually by each journal. All else equal, a journal that publishes more articles has more opportunities to engage in coercion, and/or it interacts with more authors and is more likely to be reported in our sample. Second, we control for the average number of citations per article. The average number of citations per document controls for some of the overall differences in citation practices across disciplines.

Given the large number of hypotheses to be tested, we present a compiled list of the dependent variables in Table 2. This table names the dependent variables, describes how they were constructed, and lists the tables that present the estimated coefficients pertinent to those dependent variables. Table 2 is intended to give readers an outline of the arc of the remainder of the manuscript.

Results

Honorary authorship in research manuscripts

Looking across all disciplines, 35.5% of our survey respondents report that they have added an author to a manuscript even though the contribution of those authors was minimal. Fig 1 displays tallies of some raw responses to show how the use of honorary authorship, for both manuscripts and grants, differs across science, engineering, medicine, business, and the social sciences.

To begin the empirical study of the systematic use of honorary authorship, we start with the addition of honorary authors to research manuscripts. This is a logit model in which the dependent variable equals one if the respondent felt obligated to add an author to their manuscript, "even though that individual's contribution was minimal." The estimates appear in Table 3. In brief, all of our conjectures are observed in these data. As we hypothesized above, the pressure on scholars to add authors "who do not add substantially to the research project," is more likely to be felt by assistant professors and associate professors relative to professors (the reference category). To understand the size of the effect, we calculate odds ratios (e^{β}) for each variable, also reported in Table 3. Relative to a full professor, being an assistant professor increases the odds of honorary authorship in manuscripts by 90%, being an associate professor increases those odds by 40%, and research faculty are twice as likely as a professor to add an honorary author.

Consistent with our hypothesis, we found support that females were more likely to add honorary authors as the estimated coefficient on males was negative and statistically significant. The odds that a male feels obligated to add an author to a manuscript is 38% lower than for females. As hypothesized, authors who already have several co-authors on a manuscript seem more willing to add another; consistent with our hypotheses that the decrement in individual credit diminishes as the number of authors rises. Overall, these results align with our fundamental thesis that authors are purposively deciding to deceive, adding authors when the benefits are higher and the costs lower.

Considering the addition of honorary authors to manuscripts, Table 3 shows that four disciplines are statistically more likely to add honorary authors than the average across all disciplines. Listing those disciplines in order of their odds ratios and starting with the greatest odds, they are: marketing, management, ecology, and medicine (physicians). There are five disciplines in which honorary authorship is statistically below the average and starting with the lowest odds ratio they are: political science, accounting, mathematics, chemistry, and economics. Finally, the remaining disciplines, statistically indistinguishable from the average, are: physics, psychology, sociology, computer science, finance, engineering, biology, information systems, and nursing. At the extremes, scholars in marketing are 75% more likely to feel an obligation to add authors to a manuscript than the average across all disciplines while political scientists are 44% less likely than the average to add an honorary author to a manuscript.

Table 2. List of dependent variables, a description of how those variables are constructed, and the table in which they appear.

Dependent variable	Description	Table
Honorary Authorship: Manuscripts		
Added honorary author to manuscript	Binary variable = 1 if respondent has added an honorary author to a research manuscript in the last five years; = 0 otherwise	Table 3
Number of times added authors to manuscripts	Count variable; number of times have added honorary author to manuscripts in the last five years	Table 4
Honorary Authorship: Grant Proposals		
Added honorary author to grant proposal	Binary variable = 1 if respondent has added an honorary author to a grant proposal in the last five years; = 0 otherwise	Table 5
Reasons added Honorary Authors to Manuscripts		
Director	Binary variable = 1 the primary reason this honorary author was added to a manuscript; "was the Director of the lab or facility used in the research." = 0 otherwise	Table 6
Authority	Binary variable = 1 the primary reason this honorary author was added to a manuscript; "occupies a position of authority and can influence my career." = 0 otherwise.	Table 6
Mentor	Binary variable = 1 the primary reason this honorary author was added to a manuscript, "this is my mentor." = 0 otherwise	Table 6
Reasons added Honorary Authors to Grant Proposals		
Reputation	Binary variable = 1 the primary reason this honorary author was added to a grant proposal, "their reputation increases the chances of receiving funding." = 0 otherwise	Table 7
Director	Binary variable = 1 the primary reason this honorary author was added to a grant proposal, "was the Director of the lab or facility used in the research." = 0 otherwise	Table 7
Authority	Binary variable = 1 the primary reason this honorary author was added to a grant proposal, this individual, "occupies a position of authority and can influence my career." = 0 otherwise	Table 7
Coercive Citations: individual data		
Existence of coercive citation	Binary variable = 1 if respondent was coerced by an editor to add superfluous citations to the editor's journal in the last five years. = 0 otherwise	Table 8
Frequency of coercive citation	Count variable; number of times respondent was coerced by editors to add superfluous citations to the editors' journals in the last five years.	Table 9
Coercive Citations: journal data		
Journals that have coerced	Binary data = 1 if journal was named as having coerced; = 0 otherwise	Tables 10 and 11
Frequency journals coerced authors	Count variable; number of times a journal was identified as one that practiced coercion in the last five years	Tables 10 and 11
Padded Citations		
Padded citations in manuscripts	Ordered categorical variable; Response to the statement, "If I were submitting an article to a journal with a reputation of asking for citations to itself even if those citations are not critical to the content of the article, I would probably add such citations BEFORE SUBMISSION." Strongly agree = 5; agree = 4; neutral = 3; disagree = 2; strongly disagree = 1	Table 12
Padded citations in grant proposals	Ordered categorical variable; response to the statement, "When developing a grant proposal I tend to skew my citations toward high impact factor journals even if those citations are of marginal impact to my proposal." Strongly agree = 5; agree = 4; neutral = 3; disagree = 2; strongly disagree = 1	Table 13

https://doi.org/10.1371/journal.pone.0187394.t002

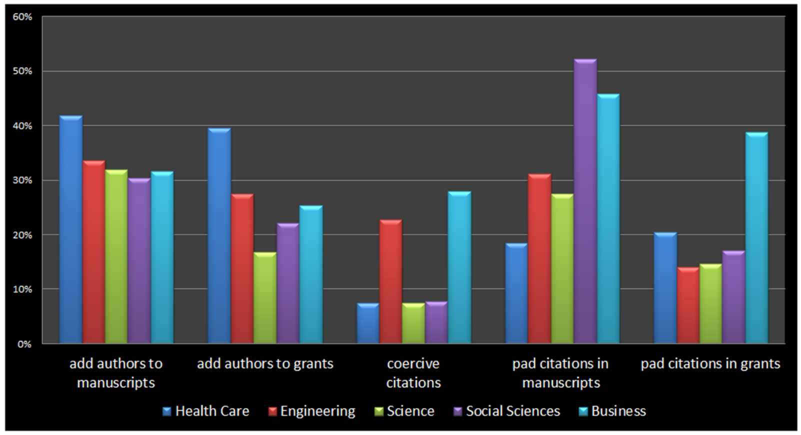

Fig 1. Manipulation of authorship and citation across academia. Percentage of respondents who report that honorary authors have been added to their research projects, they have been coerced by editor to add citations, or who have padded their citations, sorted by field of study and type of manipulation.

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To bolster these results, we also asked individuals to tell us *how many times* they felt obligated to add honorary authors to manuscripts in the last five years. Using these responses as our dependent variable we estimated a negative binomial regression equation with the same independent variables used in Table 3. The estimated coefficients and their transformation into incidence rate ratios are given in Table 4. Most of the estimated coefficients in Tables 3 and 4 have the same sign and, with minor differences, similar significance levels, which suggests the attributes associated with a higher likelihood of adding authors are also related to the frequency of that activity. Looking at the incidence rate ratios in Table 4, scholars occupying the lower academic ranks, research professors, females, and manuscripts that already have many authors more frequently add authors. Table 4 also suggests that three additional disciplines, Nursing, Biology, and Engineering, have more incidents of adding honorary authors to manuscripts than the average of all disciplines and, consequently, the disciplines that most frequently engage in honorary authorship are, by effect size, management, marketing, ecology, engineering, nursing, biology, and medicine.

Another way to measure effect sizes is to standardize the variables so that the changes in the odds ratios or incidence rate ratios measure the impact of a one standard deviation change of the independent variable on the dependent variable. In Tables 3 and 4, the continuous variables are the number of coauthors on the particular manuscripts of interest and the number of publications of each respondent. Tables C and D (in S1 Appendix) show the estimated coefficients and odds ratios with standardized coefficients. Comparing the two sets of results is instructive. In Table 3, the odds ratio for the number of coauthors is 1.035, adding each additional author increases the odds of this manuscript having an honorary author by 3.5%. The estimated odds ratio for the standardized coefficient, (Table C in S1 Appendix) is 1.10, meaning an increase in the number of coauthors of one standard deviation increases the odds that this manuscript has an honorary author by 10%. Meanwhile the standard deviation of the number of coauthors in this sample is 2.78, so 3.5% x 2.78 = 9.73%; the two estimates are very similar. This similarity repeats itself when we consider the number of publications and when we compare the incidence rate ratios across Table 4 and Table D in S1 Appendix. Standardization also tells us something about the relative effect size of different independent variables and in both models a standard deviation increase in the number of coauthors has a larger impact

Table 3. Adding honorary authors to manuscripts: Estimate coefficients and odds ratios.

Variables	Estimated coefficients	Std. error	Odds ratio	Std. error
Academic Ranks				
Assistant Professor	0.642**	0.061	1.901**	0.117
Associate Professor	0.341**	0.056	1.407**	0.079
Lecturer	0.085	0.137	1.089	0.150
Research Faculty	0.716**	0.129	2.046**	0.265
Clinical Faculty	0.411*	0.169	1.508*	0.255
Other rank	0.504**	0.127	1.655**	0.211
Gender and number of co-authors				
Male	-0.471**	0.050	0.624**	0.031
# co-authors	0.034**	0.008	1.035**	0.009
Disciplines				
Medicine	0.191**	0.055	1.211**	0.068
Nursing	0.148	0.084	1.161	0.098
Accounting	-0.615**	0.200	0.541**	0.108
Economics	-0.218*	0.094	0.804*	0.075
Finance	-0.105	0.195	0.900	0.175
Info systems	0.377	0.209	1.458*	0.305
Management	0.491**	0.089	1.634**	0.146
Marketing	0.561**	0.149	1.752**	0.262
Political Science	-0.819**	0.141	0.441**	0.062
Psychology	0.056	0.076	1.058	0.080
Sociology	0.052	0.101	1.054	0.107
Biology	0.123	0.068	1.131	0.077
Chemistry	-0.352**	0.103	0.703**	0.073
Computer Sci	0.040	0.131	1.041	0.136
Ecology	0.300**	0.113	1.349**	0.153
Engineer	0.145	0.088	1.156	0.101
Mathematics	-0.527**	0.170	0.590**	0.100
Physics	0.151	0.110	1.163	0.128
Publication history				
Publications	0.014**	0.002	1.014**	0.002
Constant	-0.986**	0.063	0.373**	0.023
	n = 9910; χ^2 = 524.11			

Logit regression, dependent variable is binary: 1 = felt obligated to add an author, 0 = did not feel obligated. Independent variables include academic ranks, disciplines, gender, number of co-authors, and the number of publications. Discipline estimates compare each discipline to the overall average across all disciplines.

* Indicates significance at the 5% level;

** significant at the 1% level.

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on the likelihood of adding another author than a standard deviation increase in additional publications.

Honorary authorship in grant proposals

Our next set of results focus on honorary authorship in grant proposals. Looking across all disciplines, 20.8% of the respondents reported that they had added an investigator to a grant proposal even though the contribution of that individual was minimal (see Fig 1 for differences

Table 4. Number of times authors added to manuscripts: Estimated coefficients and incidence rate ratios.

	Estimated coefficient	Standard Error	Incidence rate ratio	Standard error
Faculty Ranks				
Assistant Professor	0.658**	0.059	1.931**	0.113
Associate Professor	0.343**	0.054	1.409**	0.076
Lecturer	0.147	0.135	1.159	0.157
Research Faculty	0.801**	0.123	2.227**	0.274
Clinical Fac.	0.175	0.173	1.192	0.206
Other rank	0.501**	0.122	1.650**	0.201
Gender and number of co-authors				
Male	-0.266**	0.049	0.766**	0.037
Number of co-authors	0.084**	0.010	1.088**	0.010
Disciplines				
Medicine	0.138**	0.054	1.148**	0.062
Nursing	0.201*	0.083	1.223**	0.102
Accounting	-0.650**	0.199	0.552**	0.104
Economics	-0.072	0.089	0.930	0.083
Finance	-0.070	0.189	0.932	0.176
Info systems	0.254	0.209	1.289	0.269
Management	0.515**	0.087	1.674**	0.146
Marketing	0.398**	0.150	1.488**	0.222
Political Science	-0.718**	0.134	0.487**	0.065
Psychology	0.044	0.074	0.957	0.071
Sociology	0.010	0.101	0.990	0.100
Biology	0.149*	0.066	1.161*	0.076
Chemistry	-0.587**	0.104	0.555**	0.058
Computer Science	0.111	0.126	1.118	0.141
Ecology	0.325**	0.109	1.383**	0.150
Engineering	0.299**	0.083	1.348**	0.112
Mathematics	-0.317*	0.154	0.728*	0.112
Physics	0.078	0.107	1.081	0.115
Other controls				
Publications	0.025**	0.002	1.025**	0.002
Constant	-1.086**	0.063	0.337**	0.021
	n = 9929; χ^2 = 731.5			

Negative binomial regression, the dependent variable is the number of times the respondent added honorary authors to manuscripts in the last five years. Independent variables include academic ranks, disciplines, gender, number of co-authors, and the number of publications. Discipline estimates compare each discipline to the overall average across all disciplines.

* Indicates significance at the 5% level;

** significant at the 1% level.

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across disciplines). To more deeply probe into that behavior we begin with a model in which the dependent variable is binary, whether a respondent has added an honorary author, or not, to a grant proposal and thus use a logit model. With some modifications, the independent variables include the same variables as the manuscript models in Tables 3 and 4. We remove a control variable relevant to manuscripts (total number of publications) and add two control variables to measure the level of exposure a particular scholar has to the funding process: the number of grants funded in the last five years and the total amount of grant funding (dollars) in that same period.

Table 5. Adding honorary authors to grant proposals: Estimated coefficients and odds ratios.

Variables	Estimated coefficients	Std. error	Odds ratio	Std. error
Faculty Ranks				
Assistant Professor	0.523**	0.076	1.687**	0.128
Associate Professor	0.424**	0.071	1.528**	0.108
Lecturer	0.814**	0.203	2.258**	0.459
Research Faculty	0.966**	0.148	2.628**	0.388
Clinical Faculty	0.004	0.247	1.004	0.248
Other rank	0.799**	0.182	2.223**	0.405
Disciplines				
Medicine	0.792**	0.068	2.208**	0.151
Nursing	0.786**	0.104	2.195**	0.229
Accounting	0.139	0.280	1.149	0.322
Economics	0.158	0.128	1.171	0.150
Finance	0.014	0.336	1.014	0.341
Info systems	-0.032	0.335	0.968	0.325
Management	0.306**	0.131	1.358**	0.178
Marketing	-0.077	0.283	0.926	0.262
Political Sci	-0.729**	0.202	0.482**	0.097
Psychology	0.234*	0.097	1.264**	0.123
Sociology	-0.013	0.140	0.987	0.138
Biology	-0.453**	0.099	0.636**	0.063
Chemistry	-0.385**	0.138	0.680**	0.094
Computer Sci	0.061	0.171	1.063	0.181
Ecology	-0.264	0.154	0.768	0.118
Engineer	0.238*	0.110	1.269*	0.140
Mathematics	-0.457	0.243	0.633	0.154
Physics	-0.317*	0.155	0.728*	0.113
Gender and other control variables				
Male	-0.252**	0.063	0.777**	0.049
# grants	0.032**	0.004	1.032	0.004
Grant dollars	-2.40E-10	2.8E-10	1.00	2.8E-10
Constant	-1.710**	0.079	0.181**	0.014
n = 7524; χ^2 = 437.01				

Logit regression, dependent variable is binary: 1 = added author, 0 = did not add author to research. Independent variables include academic ranks, disciplines, gender, number of grants received, and total grant money received in last 5 years.

* Indicates significance at the 5% level;

** significant at the 1% level.

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The results appear in Table 5 and, again, we see significant participation in honorary authorship. The estimates largely follow our predictions and mirror the results of the models in Tables 3 and 4. Academic rank has a smaller effect, being an assistant professor increases the odds of adding an honorary author to a grant by 68% and being an associate professor increases those odds by 52%. On the other hand, the impact of being a research professor is larger in the grant proposal models than the manuscripts model of Table 3 while the impact of sex is smaller. As was true in the manuscripts models, the obligation to add honorary authors is also lumpy, some disciplines being much more likely to engage in the practice than others. We find five disciplines in the "more likely than average" category: medicine, nursing, management, engineering, and psychology. The disciplines that tend to add fewer honorary authors to grants are political science, biology, chemistry, and physics. Those that are indistinguishable from the average are accounting, economics, finance, information systems, sociology, ecology, marketing, computer science, and mathematics.

We speculated that science, engineering, and medicine were more likely to practice honorary authorship in grant proposals because those disciplines are more dependent on research funding and more likely to consider funding as a requirement for tenure and promotion. The results in Tables 3 and 5 are somewhat consistent with this conjecture. Of the five disciplines in the "above average" category for adding honorary authors to grant proposals, four (medicine, nursing, engineering, and psychology) are dependent on labs and funding to build and maintain such labs for their research.

Reasons for adding honorary authors

Our next set of results looks more deeply into the reasons scholars give for adding honorary authors to manuscripts and to grants. When considering honorary authors added to manuscripts, we focus on a set of responses to the question: "what was the major reason you felt you needed to add those co-author(s)?" When we look at grant proposals, we use responses to the survey question: "The main reason you added an individual to this grant proposal even though he (or she) was not expected to make a significant contribution was. . ." Starting with manuscripts, although nine different reasons for adding authors were cited (see survey in S1 Appendix), only three were cited more than 10% of the time. The most common reason our respondents added honorary authors (28.4% of these responses) was because the added individual was the director of the lab. The second most common reason (21.4% of these responses), and the most disturbing, was that the added individual was in a position of authority and could affect the scholar's career. Third among the reasons for honorary authorship (13.2%) were mentors. "Other" was selected by about 13% of respondents. The percentage of raw responses for each reason is shown in Fig 2.

To find out if the three most common responses were related to the professional characteristics of the scholars in our study, we re-estimate the model in Table 3 after replacing the

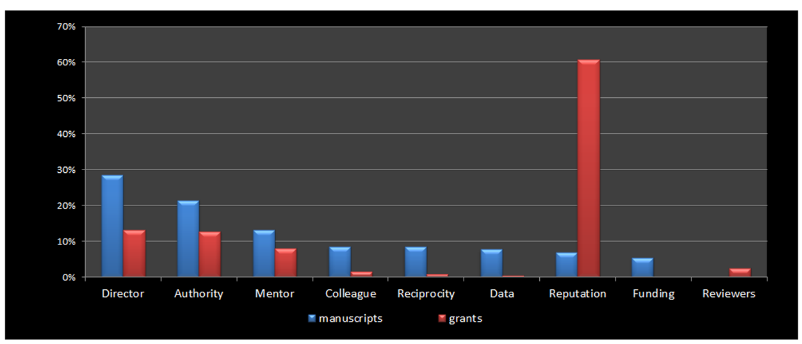

Fig 2. Reasons for adding honorary authors to grants and manuscripts. Each pair of columns presents the percentage of responses who selected a particular reason for adding an honorary author to a manuscript or a grant proposal. Director refers to responses stating, "this individual was the director of the lab or facility used in the research." Authority refers to responses stating, "this individual occupies a position of authority and can influence my career." Mentor, "this is my mentor"; colleague, "this a colleague I wanted to help"; reciprocity, "I was included or expect to be included as a co-author on their work"; data, "they had data I needed"; reputation, "their reputation increases the chances of the work being published (or funded)"; funding, "they had funding we could apply to the research"; and reviewers, "the grant reviewers suggested we add co-authors."

https://doi.org/10.1371/journal.pone.0187394.g002

Table 6. Reasons authors added to manuscripts: Estimated coefficients.

	Director of Laboratory		Position of Authority		Mentor	
	Coef.	Std. err	Coef.	Std. err	Coef.	Std. err
Academic Ranks						
Assistant Professor	-0.004	0.116	0.464**	0.128	0.925**	0.161
Associate Professor	0.047	0.110	0.383**	0.126	0.208	0.176
Lecturer	-0.369	0.331	0.374	0.298	1.373**	0.291
Research Faculty	0.414	0.211	0.487*	0.251	0.539	0.324
Clinical Faculty	0.352	0.309	-0.373	0.372	1.148**	0.347
Other Rank	0.325	0.238	0.249	0.268	0.488	0.304
Gender and number of coauthors						
Male	0.084	0.094	-0.075	0.106	-0.0207	0.134
Number of Co-authors	0.004	0.015	-0.035	0.021	-0.214**	0.036
Disciplines						
Medicine	0.863**	0.125	0.517**	0.116	0.374*	0.167
Nursing	0.371*	0.187	0.748**	0.162	0.846**	0.200
Accounting	-0.907	0.698	0.378	0.419	-0.578	0.703
Economics	-0.469	0.259	0.067	0.212	0.441	0.238
Finance	-1.635	0.965	0.219	0.441	-0.165	0.593
Info systems	0.110	0.435	0.327	0.389	1.032**	0.391
Management	-0.344	0.218	0.508**	0.162	0.691**	0.190
Marketing	-0.267	0.350	-0.053	0.309	0.541*	0.323
Political Science	-0.877	0.500	0.256	0.318	-0.721	0.573
Psychology	0.850**	0.154	-0.327	0.182	0.338	0.207
Sociology	0.100	0.233	-0.227	0.241	-0.511	0.345
Biology	0.961**	0.142	-0.726**	0.193	-0.453	0.256
Chemistry	0.858**	0.213	-0.916**	0.354	-0.505	0.416
Computer Science	-0.919*	0.412	0.393	0.265	0.093	0.374
Ecology	0.694**	0.207	-0.104	0.253	0.320	0.313
Engineering	0.704**	0.172	-0.246	0.209	-0.374	0.304
Mathematics	-0.228	0.463	-0.483	0.506	-1.30	0.965
Physics	0.100	0.242	-0.333	0.290	-0.074	0.389
Publication history						
Publications	0.005	0.003	-0.006	0.004	-0.005	0.006
Constant	-1.883**	0.137	-1.663**	0.142	-1.955**	0.203
	n = 3158; χ^2 = 138.1		n = 3158; χ^2 = 136.4		n = 3158; χ^2 = 192.75	

Logit regression, dependent variable is binary: 1 = added director of laboratory as co-author, or someone in position of authority, or a mentor (even though they were not materially involved in the research), 0 = some other reason for adding author. Independent variables include academic ranks, disciplines, gender, number of co-authors, and number of publications in last five years.

* Indicates significance at the 5% level;

** significant at the 1% level.

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dependent variable with the reasons for adding an author. In other words, the first model displayed in Table 6, under the heading "Director of Laboratory," estimates a regression in which the dependent variable equals one if the respondent added the director of the research lab in which they worked as an honorary author and equals zero if this was not the reason. The second model indicates those who added an author because he or she was in a position of authority and so forth. The estimated coefficients appear in Table 6 and the odds ratios are reported in S1 Appendix, Table E. Note the sample size is smaller for these regressions because we include only those respondents who say they have added a superfluous author to a manuscript.

The results are as expected. The individuals who are more likely to add a director of a laboratory are research faculty (they mostly work in research labs and centers), and scholars in fields in which laboratory work is a primary method of conducting research (medicine, nursing, psychology, biology, chemistry, ecology, and engineering). The second model suggests that the scholars who add an author because they feel pressure from individuals in a position of authority are junior faculty (assistant and associate professors, and research faculty) and individuals in medicine, nursing, and management. The third model suggests assistant professors, lecturers, research faculty, and clinical faculty are more likely to add their mentors as an honorary author. Since many mentorships are established in graduate school or through post-docs, it is sensible that scholars who are early in their career still feel an obligation to their mentors and are more likely to add them to manuscripts. Finally, the disciplines most likely to add mentors to manuscripts seem to be the "professional" disciplines: medicine, nursing, and business (economics, information systems, management, and marketing). We do not report the results for the other five reasons for adding honorary authors because few respondent characteristics were statistically significant. One explanation for this lack of significance may be the smaller sample size (less than 10% of the respondents indicated one of these remaining reasons as being the primary reason they added an author) or it may be that even if these rationales are relatively common, they might be distributed randomly across ranks and disciplines.

Turning to grant proposals, the dominant reason for adding authors to grant proposals even though they are not actually involved in the research was reputation. Of the more than 2100 individuals who gave a specific answer to this question, 60.8% selected "this individual had a reputation that increases the chances of the work being funded." The second most frequently reported reason for grants was that the added individual was the director of the lab (13.5%), and third was people holding a position of authority (13%). All other reasons garnered a small number of responses.

We estimate a set of regressions similar to Table 6 using the reasons for honorary grant proposal authorship as the dependent variable and the independent variables from the grant proposal models of Table 5. Before estimating those models we also add six dummy variables reflecting different sources of research funding to see if the reason for adding honorary citations differs by type of funding. These dummy variables indicate funding from NSF, HHS (which includes the NIH), research grants from private corporations, grants from private, non-profit organizations, state research grants, and then a variable capturing all other federally funded grants. The omitted category is all other grants. The estimated coefficients appear in Table 7 and the odds ratios are reported in Table F in S1 Appendix.

The first column of results in Table 7 replicates and adds to the model in Table 5, in which the dependent variable is: "have you added honorary authors to grant proposals." The reason we replicate that model is to add the six funding sources to the regression to see if some agencies see more honorary authors in their proposals than other agencies. The results in Table 7 suggest they do. Federally funded grants are more likely to have honorary authorships than other sources of grant funding as the coefficients on NSF, NIH, and other federal funding are all positive and significant at the 0.01 level. Corporate research grants also tend to have honorary authors included.

The remaining columns in Table 7 suggest that scholars in medicine and management are more likely to add honorary authors to grant proposals because of the added scholar's reputation, but there is little statistical difference across the other characteristics of our respondents. Exploring the different sources of funds, adding an individual because of his or her reputation

Table 7. Reasons authors are added to grant proposals: Estimated coefficients.

Variables	Added author		Reputation		Director		Authority	
	Coef.	Std. err	Coef.	Std. err	Coef.	Std. err	Coef.	Std. err
Academic Ranks and Gender								
Assistant	0.54**	0.09	0.31*	0.14	-0.45*	0.21	0.20	0.22
Associate	0.46**	0.08	0.22	0.13	-0.27	0.19	0.26	0.20
Lecturer	0.97**	0.23	0.36	0.37	-1.23	0.76	0.24	0.57
Res. faculty	0.87**	0.16	-0.15	0.24	0.68*	0.28	-0.22	0.43
Clinic faculty	-0.12	0.38	-0.60	0.53	0.09	0.67	1.02	0.68
Other rank	0.91**	0.19	0.24	0.31	-0.08	0.43	0.46	0.43
Male	-0.30**	0.07	0.07	0.11	-0.06	0.16	-0.12	0.17
Disciplines								
Medicine	1.37**	0.09	0.28	0.15	0.04	0.21	-0.06	0.23
Accounting	0.40	0.28	0.01	0.50	-1.03	0.98	-0.71	0.99
Economics	0.34**	0.13	0.18	0.23	-0.03	0.34	-0.67	0.43
Finance	0.25	0.34	-0.48	0.62	0.45	0.77	0.69	0.77
Info systems	-0.11	0.34	0.04	0.61	0.36	0.76	1.01	0.67
Management	0.53**	0.17	0.73**	0.24	-0.70	0.41	-0.15	0.37
Marketing	0.09	0.29	-0.16	0.52	1.72**	0.54	-0.79	0.99
Poly science	-0.56**	0.20	0.59	0.40	-0.15	0.60	0.13	0.53
Psychology	-0.07	0.10	0.06	0.19	0.34	0.26	-0.52	0.34
Sociology	-0.06	0.14	0.02	0.26	-0.58	0.46	-0.44	0.46
Biology	-0.70**	0.10	-0.23	0.19	0.01	0.29	0.11	0.28
Chemistry	-0.53**	0.14	-0.31	0.26	0.70*	0.32	0.06	0.41
Comp Science	-0.01	0.17	0.05	0.31	-0.84	0.59	0.16	0.42
Ecology	-0.24	0.16	-0.30	0.29	0.04	0.40	0.14	0.40
Engineer	0.17	0.11	0.02	0.19	0.03	0.28	0.21	0.27
Mathematics	-0.53*	0.25	-0.30	0.46	omitted		0.64	0.56
Physics	-0.34*	0.16	-0.13	0.29	-0.27	0.44	0.31	0.39
Grant history								
Number Grants	0.03**	0.01	0.01	0.01	-0.02	0.01	-0.01	0.01
Grant dollars	-.15E-9	.23E-9	-4.4E-9	4.7E-9	1.7E-9	1.E-9	-4E-9	1.4E-8
NSF	0.54**	0.11	-0.09	0.21	0.49	0.33	0.11	0.30
HHS	1.15**	0.12	0.63**	0.21	-0.09	0.34	-0.60	0.33
Corporation $	0.45*	0.21	-0.92**	0.34	1.24**	0.44	0.39	0.45
Nonprofit	0.03	0.13	-0.09	0.24	0.62	0.38	-0.23	0.38
State funding	0.26	0.15	-0.03	0.27	0.58	0.40	-0.64	0.47
Otr. FED Grants	0.63**	0.14	-0.20	0.26	0.41	0.39	0.33	0.36
Constant	-2.11**	0.12	-0.20	0.21	-1.8**	0.35	-1.94	0.33
	n = 6343; χ^2 = 893.4		n = 1711; χ^2 = 109.0		n = 1693; χ^2 = 70.6		n = 1711; χ^2 = 44.6	

Logit regression, dependent variable is binary: 1 = added an author to a grant proposal because of his or reputation, or added the director of laboratory as co-author, or someone in position of authority (even though they were not materially involved in the research), 0 = some other reason for adding author. Independent variables include academic ranks, disciplines, gender, funding agency, number of grants, and total grand funding received in last five years.

* Indicates significance at the 5% level;

** significant at the 1% level.

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is more likely to be practiced with grants to the Department of Health and Human Services (probably because of the heavy presence of medical proposals and honorary authorship is common in medicine) and it is statistically less likely to be used in grant proposals directed towards corporate research funding.

Table 7 shows that lab directors tend to be honorary authors in grant proposals with assistant professors and for grant proposals directed to private corporations. While position of authority (i.e., political power) was the third most frequently cited reason to add someone to a proposal, its practice seems to be dispersed across the academic universe as the regression results in Table 7 do not show much variation across rank, discipline, their past experience with research funding, or the funding source to which the proposal was directed. The remaining reasons for adding authors garnered a small portion of the total responses and there was little significant variation across the characteristics measured here. For these reasons, their regression results are not reported.

Coercive citations

There is widespread distaste among academics concerning the use of coercive citation. Over 90% of our respondents view coercion as inappropriate, 85.3% think its practice reduces the prestige of the journal, and 73.9% are less likely to submit work to a journal that coerces. These opinions are shared across the academic spectrum as shown in Fig 3, which breaks out these responses by the major fields, medicine, science, engineering, business, and the social sciences. Despite this disapproval, 14.1% of the overall respondents report being coerced. Similar to the analyses above, our task is to see if there is a systematic set of attributes of scholars who are coerced or if there are attributes of journals that are related to coercion.

Two dependent variables are used to measure the existence and the frequency of coercive citation. The first is a binary dependent variable, whether respondents were coerced or not, and the second counts the frequency of coercion, asking our respondents *how many times* they have been coerced in the last five years. Table 8 presents estimates of the logit model (coerced or not) and their odds ratios and Table 9 presents estimates of the negative binomial model (measuring the frequency of coercion) and their accompanying incident rate ratios. With but a single exception (the estimated coefficient on female scholars was opposite our expectation) our hypotheses are supported. In this sample, it is males who are more likely to be coerced, the effect size estimates that being a male raises the odds ratio of being coerced by 18%. In the frequency estimates in Table 9, however, there was no statistical difference between male and female scholars.

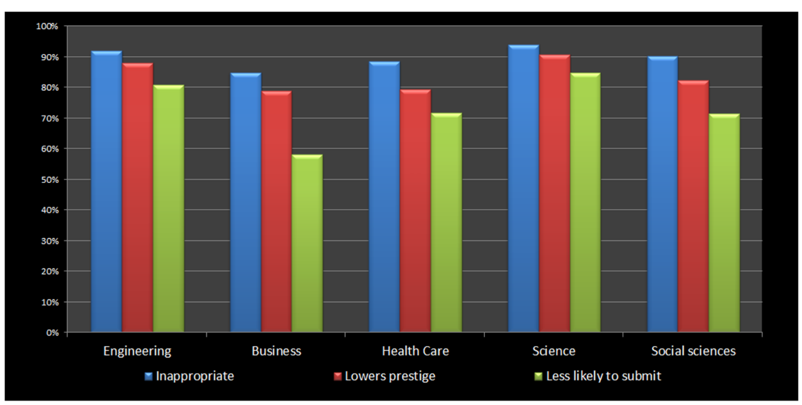

Fig 3. Disapproval of coercive citation by major academic group. The first column in each cluster presents the percentage of respondents from each major academic group who either strongly agree or agree with the statement the coercive citations, "is inappropriate." The second column is the percentage that agrees to, "[it] reduces the prestige of the journal." The third column reflects agreement to, "are less likely to submit work to a journal that coerces."

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Table 8. Existence of coercive citation: Estimated coefficients and odds ratios.

Variables	Estimated coefficient	Std. error	Odds ratio	Std. error
Academic Ranks				
Assistant professor	0.357**	0.076	1.429**	0.109
Associate professor	0.195**	0.073	1.215**	0.089
Lecturer	-0.538*	0.212	0.584*	0.124
Other faculty	0.051	0.117	1.052	0.123
Gender and number of coauthors				
Male	0.164*	0.068	1.178*	0.080
Number coauthors	-0.096**	0.018	0.908**	0.016
Disciplines				
Medicine	-0.493**	0.089	0.610**	0.055
Nursing	-0.524**	0.153	0.592**	0.090
Accounting	0.535**	0.157	1.708**	0.268
Economics	0.235*	0.102	1.265*	0.129
Finance	1.281**	0.131	3.601**	0.472
Info systems	1.306**	0.099	3.691**	0.364
Management	1.166**	0.088	3.208**	0.281
Marketing	1.364**	0.093	3.911**	0.362
Political science	-0.942**	0.235	0.390**	0.091
Psychology	-0.621**	0.116	0.537**	0.062
Sociology	-0.377*	0.138	0.686**	0.094
Biology	-0.114	0.198	0.892	0.177
Chemistry	-0.886**	0.154	0.412**	0.063
Computer science	-0.448*	0.173	0.639**	0.111
Ecology	0.778**	0.158	2.178**	0.344
Engineering	0.582**	0.090	1.789**	0.160
Mathematics	-1.625**	0.321	0.197**	0.063
Physics	-1.215**	0.225	0.297**	0.067
Publication history				
Total publications	0.028**	0.002	1.028**	0.002
Constant	-2.190**	0.099	0.112	0.011**
	n = 11567; χ^2 = 1022.9			

Logit regression, dependent variable is binary: 1 = have been coerced to add citations, 0 = have not been coerced. Independent variables include academic ranks, disciplines, gender, number of co-authors, and number of publications in last five years.

* Indicates significance at the 5% level;

** significant at the 1% level.

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Consistent with our hypotheses, assistant professors and associate professors were more likely to be coerced than full professors and the effect was larger for assistant professors. Being an assistant professor increases the odds that you will be coerced by 42% over a professor while associate professors see about half of that, a 21% increase in their odds. Table 9 shows assistant professors are also coerced more frequently than professors. Co-authors had a negative and significant coefficient as predicted in both sets of results. Consequently, comparing Tables 3 and 8 we see that manuscripts with many co-authors are more likely to add honorary authors, but are less likely to be targeted for coercion. Finally, we find significant variation across disciplines. Eight disciplines are significantly more likely to be coerced than the average across all disciplines and ordered by their odds ratios (largest to smallest) they are: marketing,

Table 9. Frequency of coercive citation: Estimated coefficients and incidence rate ratios.

Variables	Estimated Coefficient	Std. error	IncidenceRate Ratio	Std. error
Academic Ranks				
Assistant professor	0.281**	0.074	1.324**	0.097
Associate professor	0.094	0.070	1.099	0.077
Lecturer	-0.148	0.179	0.862	0.155
Other faculty	0.055	0.114	1.056	0.120
Gender and number of coauthors				
Male	0.067	0.064	1.070	0.069
Number coauthors	-0.037*	0.018	0.964*	0.017
Disciplines				
Medicine	1.946**	0.135	7.004**	0.948
Nursing	1.839**	0.252	6.287**	1.584
Accounting	0.233	0.149	1.262	0.188
Economics	0.051	0.094	1.052	0.099
Finance	0.987**	0.125	2.684**	0.336
Info systems	0.930**	0.094	2.535**	0.239
Management	0.882**	0.083	2.415**	0.200
Marketing	1.015**	0.088	2.760**	0.242
Political science	-1.115**	0.205	0.328**	0.067
Psychology	-0.848**	0.101	0.428**	0.043
Sociology	-0.590**	0.123	0.554**	0.068
Biology	-0.477**	0.175	0.621**	0.109
Chemistry	-0.923**	0.121	0.397**	0.048
Computer science	-0.736**	0.152	0.479**	0.073
Ecology	0.211	0.151	1.235	0.187
Engineering	0.280**	0.082	1.323**	0.108
Mathematics	-2.010**	0.274	0.134**	0.037
Physics	-1.676**	0.200	0.187**	0.037
Publication history				
Total publications	0.032**	0.002	1.032**	0.002
Constant	-1.659**	0.098	0.190**	0.019
	n = 8951; χ^2 = 1071.1			

Negative binomial regression, dependent variable is number of times respondents report being coerced for citations in last five years. Independent variables include academic ranks, disciplines, gender, number of co-authors, and number of publications in last five years.

* Indicates significance at the 5% level;

** significant at the 1% level.

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information systems, finance, management, ecology, engineering, accounting, and economics. Nine disciplines are less likely to be coerced and ordered by their odds ratios (smallest to largest) they are: mathematics, physics, political science, chemistry, psychology, nursing, medicine, computer science, and sociology. Again, there is support for our speculation that disciplines in which grant funding is less critical (and therefore publication is relatively more critical) experience more coercion. In the top coercion category, six of the eight disciplines are business disciplines, where research funding is less common, and in “less than average” coercion disciplines, six of the nine disciplines rely heavily on grant funding. The anomaly (and one that deserves greater study) is that the social sciences see less than average coercion even though publication is their primary measure of academic success. While they are prime targets for coercion, the editors in their disciplines have largely resisted the temptation. Again, this same pattern emerges in the frequency model. In the S1 Appendix, these models are re-estimated after standardizing the continuous variables. Results appear in Table G (existence of coercion) and Table H (frequency of coercion.)

Coercive citations: Journal data

To achieve a deeper understanding of coercive citation, we reexamine this behavior using academic journals as our unit of observation. We analyze these journal-based data in two ways: 1) a logit model in which the dependent variable equals 1 if that journal was named as having coerced and 0 if not and 2) a negative binomial model where the dependent variable is the count of the number of times a journal was identified as one where coercion occurred. As before, the variance of these data substantially exceeds the mean and thus Poison regression is inappropriate. To test our hypotheses, our included independent variables are the dummy variables for discipline, journal rank, and dummy variables for different types of publishers. We control for some of the different editorial practices across journals by including the number of documents published annually by each journal and the average number of citations per article.

The results of the journal-based analysis appear in Table 10. Once again, and consistent with our hypothesis, the differences across disciplines emerge and closely follow the previous results. The discipline journals most likely to have coerced authors for citations are in business. The effect of a journal's rank on its use of coercion is perhaps the most startling finding. Measuring journal rank using the h-index suggests that more highly rated journals are more likely to have coerced and coerced more frequently, which is opposite our hypothesis that lower ranked journals are more likely to coerce. Perhaps the chance to move from being a "good" journal to a "very good" journal is just too tempting to pass. There is some anecdotal evidence that is consistent with this result. If one surfs through the websites of journals, many simply do not mention their rank or impact factor. However, those that do mention their rank or impact tend to be more highly ranked journals (a low-ranked journal typically doesn't advertise that fact), but the very presence of the impact factor on a website suggests that the journal, or more importantly the publisher, places some value on it and, given that pressure, it is not surprising to find that it may influence editorial decisions. On the other hand, we might be observing the results of established behavior. If some journals have practiced coercion for an extended time then their citation count might be high enough to have inflated their h-index. We cannot discern a direction of causality, but either way our results suggest that more highly ranked journals end up using coercion more aggressively, all else equal.

There seems to be publisher effects as well. As predicted, journals published by private, profit oriented companies are more likely to be journals that have coerced, but it also seems to be more common in the academic associations than university publishers. Finally, we note that the total number of documents published per year is positively related to a journal having coerced and the impact of the average number of citations per document was not significantly different than zero.

The result that higher-ranked journals seem to be more inclined than lower-ranked journals to have practiced coercion warrants caution. These data contain many obscure journals; for example, there are more than 4000 publications categorized as medical journals and this long tail could create a misleading result. For instance, suppose some medical journals ranked between 1000–1200 most aggressively use the practice of coercion. In relative terms these are "high" ranked journals because 65% of the journals are ranked even lower than these clearly obscure publications. To account for this possibility, a second set of estimates was calculated after eliminating all but the "top-30" journals in each discipline. The results appear in Table 11

Table 10. Journals that have coerced: Estimated coefficients, odds ratios, and incident rate ratios (all journals).

	Coerced Authors (logit)				Frequency Coerced Authors (negative binomial)			
	Coefs.	Std. Error	Odds ratios	Std. Error	Coefs.	Std. error	IRR	Std. Error
Journal Attributes								
TotDocs	0.0002**	0.000	1.000**	0.0001	0.0002	0.0001	1.000	0.0001
RefperDoc	0.001	0.001	1.001	0.001	0.004	0.002	1.004	0.002
University	1.909	1.074	6.750	7.252	1.597	1.120	4.940	5.533
Academic	2.386*	1.062	10.867*	11.548	2.183*	1.108	8.870*	9.830
Private	2.625*	1.060	13.812*	14.639	2.421*	1.103	11.254*	12.419
Disciplines								
Medicine	-1.633**	0.136	0.195**	0.026	-1.862**	0.143	0.155**	0.022
Nursing	0.271	0.281	1.311	0.369	-0.070	0.335	0.932	0.313
Accounting	1.097	0.587	2.994	1.759	1.656**	0.608	5.240**	3.188
Economics	0.570**	0.204	1.768**	0.362	0.922**	0.210	2.515**	0.529
Finance	1.693**	0.205	5.437**	1.113	1.662**	0.266	5.272**	1.402
Info Sys	1.669**	0.259	5.307**	1.376	1.592**	0.342	4.914**	1.680
Management	1.111**	0.148	3.037**	0.449	0.966**	0.180	2.628**	0.473
Marketing	2.110**	0.382	8.251**	3.156	2.871**	0.508	17.651**	8.977
Polysci	-1.056	0.561	0.348	0.195	-0.528	0.415	0.590	0.245
Psychology	-0.040	0.185	0.961	0.178	-0.077	0.198	0.925	0.183
Sociology	-0.836**	0.179	0.433**	0.078	-0.950**	0.182	0.387**	0.070
Biology	-1.850**	0.176	0.157**	0.028	-2.209**	0.191	0.110**	0.021
Chemistry	-0.913**	0.222	0.401**	0.089	-1.191**	0.254	0.304**	0.077
CompSci	-0.321	0.196	0.725	0.142	0.140	0.188	1.151	0.216
Ecology	-0.476**	0.180	0.621**	0.112	-0.731**	0.192	0.481**	0.092
Engineering	-0.416**	0.149	0.659**	0.098	-0.384*	0.152	0.681*	0.104
Mathematics	-0.400	0.213	0.670	0.143	-0.670**	0.231	0.511**	0.118
Physics	-0.580**	0.198	0.560**	0.111	-1.138**	0.248	0.320**	0.080
Journal Rankings								
h-Index	0.022**	0.001	1.022**	0.001	0.031**	0.002	1.000**	0.0002
Constant	-6.128**	1.063	0.002**	0.002	-6.033**	1.106	1.004**	0.002
	N = 16,651; χ^2 = 873.42				N = 16,651; χ^2 = 778.55			

The unit of observation is a journal. The dependent variable for the logit model is binary: 1 = journal named as having coerced, 0 = not so named, and for the frequency model the dependent variable is the number of times a journal was named as one that has coerced. Independent variables include the total number of documents published by the journal in a year, the average references per document, the type of publisher, academic disciplines, and the journal's ranking as measured by the h-index.

* Indicates significance at the 5% level;

** significant at the 1% level.

https://doi.org/10.1371/journal.pone.0187394.t010

and generally mirror the results in Table 10. Journals in the business disciplines are more likely to have used coercion and used it more frequently than the other disciplines. Medicine, biology, and computer science journals used coercion less. However, even concentrating on the top 30 journals in each field, the h-index remains positive and significant; higher ranked journals in those disciplines are more likely to have coerced.

Padded reference lists

Our final empirical tests focus on padded citations. We asked our respondents that if they were submitting an article to a journal with a reputation of asking for citations even if those

Table 11. Journals that have coerced, top 30 journals: Estimated coefficients, odds ratios, and incident rate ratios.

	Coerced Authors (logit)				Frequency Coerced Authors (negative binomial)			
	Coefs.	Std. Error	Odds Ratio	Std. Error	Coefs.	Std. Error	IRR	Std. Error
Journal Attributes								
TotDocs	0.001	0.001	1.000	0.001	0.001	0.001	1.000	0.001
RefperDoc	-0.008*	0.004	0.992*	0.004	-0.009	0.005	0.991	0.005
University	-0.049	0.433	0.952	0.412	-0.471	0.458	0.624	0.286
Academic	0.297	0.250	1.346	0.337	0.248	0.248	1.282	0.317
Disciplines								
Medicine	-2.780**	0.757	0.062**	0.047	-2.461**	0.662	0.085**	0.056
Nursing	0.565	0.460	1.760	0.810	0.052	0.499	1.054	0.526
Accounting	0.073	0.650	1.075	0.699	0.678	0.533	1.969	1.050
Economics	-0.295	0.543	0.744	0.404	-0.794	0.598	0.452	0.270
Finance	1.998**	0.400	7.373**	2.953	1.991**	0.370	7.324**	2.709
Info systems	1.108**	0.423	3.027**	1.282	1.675**	0.371	5.339**	1.984
Management	2.207**	0.406	9.093**	3.692	2.019**	0.362	7.531**	2.723
Marketing	1.504**	0.439	4.502**	1.975	2.823**	0.353	16.836**	5.944
Polysci	-0.556	0.734	0.574	0.421	-0.068	0.573	0.934	0.536
Psychology	0.037	0.441	1.038	0.457	-0.441	0.479	0.643	0.308
Sociology	0.212	0.463	1.236	0.572	0.120	0.444	1.128	0.501
Biology	-2.108**	0.687	0.121**	0.083	-1.974**	0.669	0.139**	0.093
Chemistry	-0.445	0.458	0.641	0.293	-1.046*	0.479	0.351*	0.168
CompSci	-2.577**	0.979	0.076**	0.074	-3.009**	1.011	0.049**	0.050
Ecology	0.129	0.404	1.137	0.459	1.027**	0.360	2.794**	1.007
Engineering	0.273	0.395	1.314	0.520	0.051	0.384	1.052	0.404
Mathematics	0.315	0.427	1.371	0.585	-0.203	0.446	0.816	0.364
Physics	0.339	0.438	1.403	0.615	-0.442	0.458	0.643	0.294
Journal Ranking								
h-Index	0.011**	0.003	1.011**	0.003	0.012**	0.003	1.012**	0.003
Constant	-2.073**	0.351	0.126	0.044	-1.705	0.388	0.182	0.071
	N = 540; χ^2 = 73.87				N = 540; χ^2 = 127.21			

Table 11 repeats analysis in Table 10 cutting sample to include only the top 30 journals in each discipline as measured by the h-index. The dependent variable for the logit model is binary: 1 = journal named as having coerced, 0 = not so named, and for the frequency model the dependent variable is the number of times a journal was named as one that has coerced. Independent variables include the total number of documents published by the journal in a year, the average references per document, the type of publication, academic disciplines, and the journal's ranking as measured by the h-index.

* Indicates significant at the 5% level;

** significant at the 1% level.

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citations are not critical to the content of the article, would you "add such citations BEFORE SUBMISSION." Again, more than 40% of the respondents said they agreed with that sentiment. Regarding grant proposals, 15% admitted to adding citations to their reference list in grant proposals "even if those citations are of marginal import to my proposal."

To see if reference padding is as systematic as the other types of manipulation studied here, we use the categorical responses to the above questions as dependent variables and estimate ordered logit models using the same descriptive independent variables as before. The results for padding references in manuscripts and grant proposals appear in Tables 12 and 13, respectively. Once more, with minor deviation, our hypotheses are strongly supported.

Table 12. Padding citations in manuscripts: Estimated coefficients and odds ratios.

Variables	Estimated coefficients	Std. error	Odds ratios	Std. error
Academic Ranks				
Assistant Professor	0.752**	0.047	2.121**	0.100
Associate Professor	0.479**	0.045	1.615**	0.073
Lecturer	0.593**	0.109	1.810**	0.196
Other faculty	0.420**	0.062	1.522**	0.094
Gender and number of co-authors				
Male	-0.325**	0.040	0.722**	0.028
Coauthors	0.008	0.008	1.007	0.008
Disciplines				
Medicine	-0.913**	0.044	0.401**	0.018
Nursing	-1.168**	0.071	0.311**	0.022
Accounting	0.968**	0.113	2.632**	0.298
Economics	0.628**	0.066	1.874**	0.123
Finance	0.551**	0.111	1.734**	0.192
Information Systems	0.539**	0.081	1.714**	0.139
Management	0.862**	0.071	2.367**	0.167
Marketing	0.913**	0.078	2.493**	0.195
Political Science	0.440**	0.101	1.553**	0.156
Psychology	0.280**	0.058	1.323**	0.076
Sociology	0.562**	0.072	1.754**	0.126
Biology	-0.704**	0.105	0.495**	0.052
Chemistry	-0.452**	0.065	0.636**	0.042
CompSci	-0.450**	0.090	0.637**	0.057
Ecology	-0.169	0.105	0.844	0.089
Engineering	-0.384**	0.062	0.618**	0.042
Mathematics	-0.752**	0.094	0.471**	0.044
Physics	-0.750**	0.082	0.472**	0.039
Publication history				
Publications	-0.003*	0.001	0.997*	0.001
Aware of coercion	0.398**	0.042	1.489**	0.062
Coerced	0.451**	0.058	1.570**	0.091
n = 11,518; χ^2 = 2262.9				

Ordered logit regression, dependent variable is categorical: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree; to the likelihood of padding citations (see survey in supplemental materials). Independent variables include academic ranks, disciplines, gender, number of co-authors, number of publications, and awareness of editorial coercion.

* Indicates significance at the 5% level;

** significant at the 1% level.

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Tables 12 and 13 show that scholars of lesser rank and those without tenure are more likely to pad citations to manuscripts and skew citations in grant proposals than are full professors. The gender results are mixed, males are less likely to pad their citations in manuscripts, but more likely to pad references in grant proposals. It is the business disciplines and the social sciences that are more likely to pad their references in manuscripts and business and medicine who pad citations on grant proposals. In both situations, familiarity with other types of manipulation has a strong, positive correlation with the likelihood that individuals pad their

Table 13. Padding citations in grant proposals: Estimated coefficients and odds ratios.

Variables	Estimated coefficients	Std. error	Odds ratios	Std. errors
Academic Ranks				
Assistant Professor	0.346**	0.059	1.413**	0.084
Associate Professor	0.072	0.053	1.075	0.057
Lecturer	0.615**	0.169	1.849**	0.313
Other faculty	-0.154	0.148	0.857	0.127
Research fac.	0.209	0.126	1.232	0.155
Clinical fac.	0.584**	0.196	1.793**	0.352
Gender				
Male	0.213**	0.049	1.238**	0.061
Disciplines				
Medicine	0.050	0.054	1.051	0.057
Nursing	-0.272**	0.087	0.762**	0.066
Accounting	0.437*	0.204	1.547*	0.315
Economics	0.536**	0.092	1.710**	0.158
Finance	1.277**	0.235	3.588**	0.844
Information Systems	-0.114	0.249	0.892	0.222
Management	0.752**	0.102	2.121**	0.216
Marketing	0.668**	0.200	1.951**	0.390
Political Science	0.182	0.116	1.199	0.139
Psychology	-0.496**	0.074	0.609**	0.045
Sociology	-0.244*	0.101	0.784*	0.079
Biology	-0.190**	0.065	0.827**	0.053
Chemistry	-0.183*	0.090	0.833*	0.075
CompSci	-0.421**	0.129	0.656**	0.085
Ecology	-0.270**	0.106	0.763**	0.080
Engineering	-0.434**	0.085	0.648**	0.055
Mathematics	-0.728**	0.153	0.483**	0.074
Physics	-0.550**	0.102	0.577**	0.059
Grant history				
# grants	-0.002	0.003	0.998	0.003
Grant dollars	0.000	0.000	1.000	1.1E-09
Added authors	0.798**	0.052	2.221**	0.116
	n = 7487; χ^2 = 620.6			

Ordered logit regression, dependent variable is categorical: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree; to the likelihood of padding citations (see survey in supplemental materials). Independent variables include academic ranks, disciplines, gender, number of co-authors, number of grants received, total grant money received in last 5 years, and awareness of editorial coercion.

* Indicates significance at the 5% level;

** significant at the 1% level.

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reference list. That is, respondents who are aware of coercive citation and those who have been coerced in the past are much more likely to pad citations before submitting a manuscript to a journal. And, scholars who have added honorary authors to grant proposals are also more likely to skew their citations to high-impact journals. While we cannot intuit the direction of causation, we show evidence that those who manipulate in one dimension are willing to manipulate in another.

Discussion

Our results are clear; academic misconduct, specifically misattribution, spans the academic universe. While there are different levels of abuse across disciplines, we found evidence of honorary authorship, coercive citation, and padded citation in every discipline we sampled. We also suggest that a useful construct to approach misattribution is to assume individual scholars make deliberate decisions to cheat after weighing the costs and benefits of that action. We cannot claim that our construct is universally true because other explanations may be possible, nor do we claim it explains all misattribution behavior because other factors can play a role. However, the systematic pattern of superfluous authors, coerced citations, and padded references documented here is consistent with scholars who making deliberate decisions to cheat after evaluating the costs and benefits of their behavior.

Consider the use of honorary authorship in grant proposals. Out of the more than 2100 individuals who gave a specific reason as to why they added a superfluous author to a grant proposal, one rationale outweighed the others; over 60% said they added the individual because of they thought the added scholar's reputation increased their changes of a positive review. That behavior, adding someone with a reputation even though that individual isn't expected to contribute to the work was reported across disciplines, academic ranks, and individuals' experience in grant work. Apparently, adding authors with highly recognized names to grant proposals has become part of the game and is practiced across disciplines and rank.

Focusing on manuscripts, there is more variation in the stated reasons for honorary authorship. Lab directors are added to papers in disciplines that are heavy lab users and junior faculty members are more likely to add individuals in positions of authority or mentors. Unlike grant proposals, few scholars add authors to manuscripts because of their reputation. A potential explanation for this difference is that many grant proposals are not blind reviewed, so grant reviewers know the research team and can be influenced by its members. Journals, however, often have blind referees, so while the reputation of a particular author might influence an editor it should not influence referees. Furthermore, this might reflect the different review process of journals versus funding agencies. Funding agencies specifically consider the likelihood that a research team can complete a project and the project's probability of making a significant contribution. Reputation can play a role in setting that perception. Such considerations are less prevalent in manuscript review because a submitted work is complete—the refereeing question is whether it is done well and whether it makes a significant contribution.

Turning to coercive citations, our results in Tables 8 and 9 are also consistent with a model of coercion that assumes editors who engage in coercive citation do so mindfully; they are influenced by what others in their field are doing and if they coerce they take care to minimize the potential cost that their actions might trigger. Parallel analyses using a journal data base are also consistent with that view. In addition, the distinctive characteristics of each dataset illuminate different parts of the story. The author-based data suggests editors target their requests to minimize the potential cost of their activity by coercing less powerful authors and targeting manuscripts with fewer authors. However, contrary to the honorary authorship results, females are less likely to be coerced than males, *ceteris paribus*. The journal-based data adds that it is higher-ranked journals that seem to be more inclined to take the risk than lower ranked journals and that the type of publisher matters as well. Furthermore, both approaches suggest that certain fields, largely located in the business professions, are more likely to engage in coercive activities. This study did not investigate why business might be more actively engaged in academic misconduct because there was little theoretical reason to hypothesize this relationship. There is however some literature suggesting that ethics education in business schools has declined [34]. For the last 20–30 years business schools have turned to the mantra that stock holder value is the only pertinent concern of the firm. It is a small step to imagine that citation counts could be viewed as the only thing that matters for journals, but additional research is needed to flesh out such a claim.

Again, we cannot claim that our cost-benefit model of editors who try to inflate their journal impact factor score is the only possible explanation of coercion. Even if editors are following such a strategy, that does not rule out additional considerations that might also influence their behavior. Hopefully future research will help us understand the more complex motivations behind the decision to manipulate and the subsequent behavior of scholars.

Finally, it is clear that academics see value in padding citations as it is a relatively common behavior for both manuscripts and grants. Our results in Tables 12 and 13 also suggest that the use of honorary authorship and padding citations in grant proposals and coercive citation and padding citations in manuscripts is correlated. Scholars who have been coerced are more likely to pad citations before submitting their work and individuals who add authors to manuscripts also skew their references on their grant proposals. It seems that once scholars are willing to misrepresent authorship and/or citations, their misconduct is not limited to a single form of misattribution.

It is difficult to examine these data without concluding that there is a significant level of deception in authorship and citation in academic research and while it would be naïve to suppose that academics are above such scheming to enhance their position, the results suggest otherwise. The overwhelming consensus is that such behavior is inappropriate, but its practice is common. It seems that academics are trapped; compelled to participate in activities they find distasteful. We suggest that the fuel that drives this cultural norm is the competition for research funding and high-quality journal space coupled with the intense focus on a single measure of performance, the number of publications or grants. That competition cuts both ways, on the one hand it focuses creativity, hones research contributions, and distinguishes between significant contributions and incremental advances. On the other hand, such competition creates incentives to take shortcuts to inflate ones' research metrics by strategically manipulating attribution. This puts academics at odds with their core ethical beliefs.

The competition for research resources is getting tighter and if there is an advantage to be gained by misbehaving then the odds that academics will misbehave increase; left unchecked, the manipulation of authorship and citation will continue to grow. Different types of attribution manipulation continue to emerge; citation cartels (where editors at multiple journals agree to pad the other journals' impact factor) and journals that publish anything for a fee while falsely claiming peer-review are two examples [30, 35].

It will be difficult to eliminate such activities, but some steps can probably help. Policy actions aimed at attribution manipulation need to reduce the benefits of manipulation and/or increase the cost. One of the driving incentives of honorary authorship is that the number of publications has become a focal point of evaluation and that number is not sufficiently discounted by the number of authors [36]. So, if a publication with x authors counted as 1/x publications for each of the authors, the ability to inflate one's vita is reduced. There are problems of course, such as who would implement such a policy, but some of these problems can be addressed. For example if the online, automated citation counts (e.g., h-index, impact factor, calculators such as SCOPUS and Google Scholar) automatically discounted their statistics by the number of authors, it could eventually influence the entire academe. Other shortcomings of this policy is that this simple discounting does not allow for differential credit to be given that may be warranted, nor does it remove the power disparity in academic ranks. However, it does stiffen the resistance to adding authors and that is a crucial step.

An increasing number of journals, especially in medicine, are adopting authorship guidelines developed by independent groups, the most common being set forth by the International

Committee of Medical Journal Editors (ICMJE) [37]. To date, however, there is little evidence that those standards have significantly altered behavior; although it is not clear if that is because authors are manipulating in spite of the rules, if the rules are poorly enforced, or if they are poorly designed from an implementation perspective [21]. Some journals require authors to specifically enumerate each author's contribution and require all of the authors to sign off on that division of labor. Such delineation would be even more effective if authorship credit was weighted by that division of labor. Additional research is warranted.

There may be greater opportunities to reduce the practice of coercive citation. A fundamental difference between coercion and honorary authorship is the paper trail. Editors write down such "requests" to authors, therefore violations are easier to document and enforcement is more straightforward. First, it is clear that impact factors should no longer include self-citations. This simple act removes the incentive to coerce authors. Reuters makes such calculations and publishes impact factors including and excluding self-citations. However, the existence of multiple impact factors gives journals the opportunity to adopt and advertise the factor that puts them in the best light, which means that journals with editors who practice coercion can continue to use impact factors that can be manipulated. Thus, self-citations should be removed from all impact factor calculations. This does not eliminate other forms of impact factor manipulation such as posting accepted articles on the web and accumulating citations prior to official publication, but it removes the benefit of editorial coercion and other strategies based on inflating self-citation [38]. Second, journals should explicitly ban their editors from coercing. Some journals are taking these steps and while words do not insure practice, a code of ethics reinforces appropriate behavior because it more closely ties a journal's reputation to the practices of its editors and should increase the oversight of editorial boards. Some progress is being made on the adoption of editorial guidelines, but whether they have any impact is currently unknown [39, 40].

These results also reinforce the idea that grant proposals be double blind-reviewed. Blind-review shifts the decision calculus towards the merit of a proposal and reduces honorary authorship incentives. The current system can inadvertently encourage misattribution. For example, scholars are often encouraged to visit granting agencies to meet with reviewers and directors of programs to talk about high-interest research areas. Such visits make sense, but it is easy for those scholars to interpret their visit as a name-collecting exercise; finding people to add to proposals and collecting references to cite. Fourth, academic administrators, Provosts, Deans, and Chairs need to have clear rules concerning authorship. Far too many of our respondents said they added a name to their work because that individual could have an impact on their career. They also need to have guidelines that address the inclusion of mentors and lab directors to author lists. Proposals that include name-recognizable scholars for only a small proportion of the grant should be viewed with suspicion. This is a consideration in some grant opportunities, but that linkage can be strengthened. Finally, there is some evidence that mentoring can be effective, but there is a real question as to whether mentors are teaching compliance or how to cheat [41].

There are limitations in this study. Although surveys have shortcomings such as self-reporting bias, self-selection issues, etc., there are some issues for which surveys remain as the data collection method of choice. Manipulation is one of these issues. It would be difficult to determine if someone added honorary authors or padded citations prior to submission without asking that individual. Similarly, coercion is most directly addressed by asking authors if editors coerced them for citations. Other approaches, such as examining archival data, running experiments, or building simulations, will not work. Thus, despite its shortcomings, survey is the method of choice.

Our survey was sent via email and the overall response rate was 10.5%, which by traditional survey standards may be considered to be low. We have no data on how many surveys were filtered as spam or otherwise ended up in junk mail folders or how many addresses were obsolete. We recognize however that there is a rising hesitancy by individuals to click on an emailed link and that is what we were asking our recipients to do. For these reasons, we anticipated that our response rate may be low and compensated by increasing the number of surveys sent out. In the end, we have over 12,000 responses and found thousands of scholars who have participated in manipulation. In the S1 appendix, Table A presents response rates by discipline and while there is variation across disciplines, that variation does not correlate with any of the fundamental results, that is, there does not seem to be a discipline bias arising from differential response rates.

A major concern when conducting survey research is that the sample may not represent the population. To address this possible issue in our study, we perform various statistical analyses to determine if we encountered sampling bias. First, we compared two population demographics (sex and academic rank) to the demographics of our respondents (see Table B in S1 Appendix). The percentage of males and females in each discipline was very close to the reported sex of the respondents. There was greater variation in academic ranks with the rank of full professor being over-represented in our sample. One should keep this in mind when interpreting our findings. However, our hypotheses and results suggest that professors are the least likely to be coerced, use padded citations, and use honorary authorship, consequently our results may actually under-estimate the incidence of manipulation. Perhaps the greatest concern of potential bias innate in surveys comes from the intuition that individuals who are more intimately affected by a particular issue are more likely to respond. In the current study, it is plausible that scholars who have been coerced, or felt obligated to add authors to manuscripts, or have added investigators to grants proposals, are upset by that consequence and more likely to respond. However, if that motivation biased our responses it should show up in the response rates across disciplines, i.e., disciplines reporting a greater incidence of manipulation should have higher percentage of their population experiencing manipulation and thus higher response rates. The rank correlation coefficient between discipline response rates and the proportion of scholars reporting manipulation is $r_s = -0.181$, suggesting virtually no relationship between the two measures.

In the end, we cannot rule out the existence of bias but we find no evidence that suggests it affects our results. We are left with the conclusion that scholars manipulate attribution adding honorary authors to their manuscripts and false investigators to their grant proposals, and some editors coerce scholars to add citations that are not pertinent to their work. It is unlikely that this unethical behavior can be totally eliminated because academics are a competitive, intelligent, and creative group of individuals. However, most of our respondents say they want to play it straight and therefore, by reducing the incentives of misbehavior and raising the costs of inappropriate attribution, we can expect a substantial portion of the community to go along. With this inherent support and some changes to the way we measure scientific contributions, we may reduce attribution misbehavior in academia [42].

Supporting information

S1 Appendix. Statistical methods, surveys, and additional results.
(DOCX)

S2 Appendix. Honorary authors data.
(XLS)

S3 Appendix. Coercive citation data.
(XLS)

S4 Appendix. Journal data.
(XLS)

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Scientific misbehavior in economics

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ABSTRACT

This study reports the results of a survey of professional, mostly academic economists about their research norms and scientific misbehavior. Behavior such as data fabrication or plagiarism are (almost) unanimously rejected and admitted by less than 4% of participants. Research practices that are often considered "questionable," e.g., strategic behavior while analyzing results or in the publication process, are rejected by at least 60%. Despite their low justifiability, these behaviors are widespread. Ninety-four percent report having engaged in at least one unaccepted research practice. Surveyed economists perceive strong pressure to publish. The level of justifiability assigned to different misdemeanors does not increase with the perception of pressure. However, perceived pressure is found to be positively related to the admission of being involved in several unaccepted research practices. Although the results cannot prove causality, they are consistent with the notion that the "publish or perish" culture motivates researchers to violate research norms.

1. Introduction

The disclosure of scientific misbehavior usually causes great indignation by other scientists, the media, and the public. Even though scandals are rare, their existence fundamentally questions the image of science as a quest for truth. Scientific fraud distorts scholarly knowledge, thereby hampering and misleading scientific progress. However, trust in scientific research is also grounded on the assumption that it is unbiased by the researchers' presumptions or strategic behavior. In recent years, the focus on plagiarism and falsification has been given up in favor of an approach that also deals with questionable or "normal misbehavior" (De Vries et al., 2006). This includes practices applicable to a researcher's everyday tasks and goals. They can be as damaging to scientific progress as outright fraud. The aim of this paper is to provide evidence on fraudulent and questionable research practices in economics.

Any attempt to quantify the extent of scientific misbehavior must account for the issue that researchers have strong incentives to hide misbehavior. A popular approach is asking scientists directly. To the author's knowledge, four surveys gather evidence on certain types of misbehavior in economics (List et al., 2001; Enders and Hoover, 2004, 2006; Wilhite and Fong, 2012). The studies show that economics is subject to misbehavior. However, a broader knowledge of the research practices that economists consider unjustifiable and the prevalence of these practices is lacking.

An important question is why unaccepted research practices are employed. The most frequently cited cause is pressure to "publish or perish" (e.g., Frey, 2003; De Rond and Miller, 2005). Science has been compared to a winner-take-all market in which rewards are only granted to those first to make a discovery and therefore obtain recognition from peers (Stephan, 1996). The publication record has become increasingly important for survival in academia (e.g., Graber and Walde, 2008). At the same time, competition for publication space in top-journals has strongly increased (Franzoni et al., 2011; Card and DellaVigna, 2013). The economic theory of crime predicts that fierce competition increases the benefits of cheating (Becker, 1968). Fanelli (2010a) and Schwieren and Weichselbaumer (2010) provide evidence that cheating is more common in competitive environments. However, little is known about the link between pressure perceived by researchers and their misbehavior.

In autumn 2010, an anonymous online survey was conducted among the 2520 members of the European Economic Association (EEA), the professional body of economists from European and other countries.[1] In order to better understand which practices constitute scientific misbehavior, economists were asked to

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[1] A description of the results from a follow-up survey of German economists that had not participated in the survey of EEA members is provided in Necker (2012).

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0048-7333/

assess the justifiability of a wide range of behaviors. Respondents were surveyed about their own research practices and the expected and observed behavior of colleagues. The survey inquired into economists' perception of pressure and professional situation. A total of 631 economists responded to the survey; 426 continued until the last page.

This study examines the survey responses. Economists' acceptance of various research practices, the admitted use of those practices and evidence of misbehaving colleagues, as well as the perception of pressure are reported. The study provides the first examination of the link between perceived pressure and admitted misbehavior.

2. Previous literature

Extrapolating scientific misbehavior from disclosures is likely to capture only the tip of the iceberg (e.g., Steneck, 2006). The prevalence of positive or statistically significant results may be indicative of the use of questionable practices (e.g., Fanelli, 2010b; Brodeur et al., 2013). However, studies detecting irregularities only hint at anomalies and allow no inferences as to which practices were employed. A popular approach is the survey of researchers (e.g., Martinson et al., 2005; Titus et al., 2008).

The first survey of economists was conducted by List et al. (2001). The authors gathered information from the participants of the 1998 meetings of the American Economic Association. Falsification of data is admitted by 4.5% of the respondents. Up to 10% report having committed other misdemeanors such as having accepted or given unjustified co-authorship. The participants believe that 5–7% of research in the top 30 journals are falsified and that 13–17% are affected by other misdemeanors. List et al. (2001) cite the "Muhammad Ali effect" as an explanation for the discrepancy between admitted own behavior and the expected behavior of others. The term originates from the psychological literature. It is used to describe the finding that people see themselves as more moral than others (Allison et al., 1989).

The nature and extent of plagiarism are investigated by Enders and Hoover (2004). The authors surveyed editors from various economic journals. About 80% answer that unattributed sentences or the use of privately collected data without permission constitute plagiarism. Even more agree that this applies to unattributed proofs from working or published papers. In a typical year, a case of plagiarism is experienced by 29% of the responding editors. In a follow-up survey of "rank and file" economists almost one quarter reports that they have been plagiarized (Enders and Hoover, 2006). However, the authors stress that this number is likely to be biased by a disproportionately high participation rate of victims of plagiarism.

Wilhite and Fong (2012) analyze the prevalence of coercive citation. The authors surveyed researchers in economics, sociology, psychology, and multiple business disciplines in the US. Citation requests which are not based on a perceived omission in the academic content but on the desire to increase citations to the editor's home journal are considered inappropriate by 86% of the respondents. Having been asked to add citations for that reason is reported by 19.7%. Only 10% of those rejected the request. While the occurrence of coercion by journals in the fields of economics, psychology, and sociology is similar, journals in the business disciplines coerce more.

3. The survey

3.1. Survey methodology

When designing a survey on a topic like scientific misbehavior, it is important to minimize the likelihood that factors like perceived intrusiveness, fear of disclosure, or reluctance to admit socially undesirable attitudes or behavior affect the responses. Self-administration of questionnaires, in particular the privacy offered by an online survey, has been shown to decrease social desirability-biases (compared to personal interviews or paper forms) (Tourangeau and Yan, 2007). Confidentiality assurances have been found to increase unit and item response rates as well as the response quality when the requested data are sensitive (however, when the topic is non-sensitive assurances may arouse suspicion and backfire) (Singer et al., 1992, 1995).

The survey was administered online via SoSci Survey. The committee of the EEA sent an email to all members of the organization, inviting them to participate. The message included a non-personalized link to the questionnaire. Access was granted without a password. The invitation and introduction to the survey contained a confidentiality assurance in which anonymity was guaranteed. It was emphasized that the data would only be used in statistical analyses. The survey was accessible for eight weeks. Four weeks after the initial invitation a reminder was sent.

The first part of the survey dealt with the justifiability of different research practices. To get a broad picture of unacceptable behavior, various research practices were selected for evaluation. To explore the prevalence of misbehavior, respondents were asked whether they "have ever" engaged these practices and how many cases of researchers committing scientific misconduct they had direct evidence of. Finally, the perception of the research conditions and details on the personal situation were surveyed. The text of the questionnaire can be found in Section A of the Supplementary material (available online).

3.2. Non-response and representativeness

The population of the survey consists of all registered members of the EEA, i.e., 2520 individuals (assuming that all email addresses were available and correct). The questionnaire was started 631 times; 426 respondents continued until the last page. This amounts to a response rate of 25%, or 16.9% if dropouts are not counted. The sample is restricted to respondents who proceeded until the last page.

To check the representativeness of the sample, survey participants are compared to EEA members. Information on the location of workplace and gender are available for the sample and the population.[2] The sample is largely representative with respect to both characteristics. While 23% of survey participants are females, the EEA has 26.8% female members. The fraction of respondents working in a country corresponds to the fraction of members from that country, the correlation is 0.98.

An established procedure to check for biases caused by unit non-response is the comparison of responses from early and late respondents. The approach rests on the assumption that early respondents have a particular interest in the topic and answer the questionnaire immediately. Late respondents are assumed to be more similar to non-respondents since they would have fallen into that category if the reminder had not been sent (Armstrong and Overton, 1977). Two sample mean comparison tests show that the answers of the first and last quintile of respondents are similar.

The same result is obtained if responses from participants that continued until the last page and those that dropped out are compared. Two sample mean comparison tests show that with few

[2] The information on EEA members was kindly provided by Gemma Prunner-Thomas, EEA.

exceptions the justifiability of research practices is not significantly different between those that finished and those that dropped out.[3]

Two subsequent waves of the survey were conducted among members of the German and French economic associations.[4] In these waves, the questions on own (mis-)behavior were not posed to one sixth of randomly selected participants. The aim of this setup was to study whether surveying own behavior biases the answers. A comparison of responses from the randomly selected respondents to those from respondents answering all questions shows no significant differences (Necker, 2012).

Another issue is item non-response. Since item non-response rates are rather low (average missing rate 2.8%), all descriptive statistics are based on observed data. However, deleting observations with missing values implies an up to 14% smaller sample available for the empirical analysis. The missing values are filled in using an iterative multiple imputation (MI) procedure (Rubin, 1987, 1996). Five complete data sets were created. The details of the imputation are provided in Section B of the Supplementary material (available online).

4. Description of the data

4.1. Economists' norms

Respondents were asked "On a scale from 1 to 6 where 1 means "not at all justifiable (strongly agree)" and 6 means "highly justifiable (strongly disagree)," how do you assess the following behavior?" To test the internal consistency of the scale (interrelatedness of items), Cronbach's alpha is calculated. The α is 0.82. According to common rules of thumb, the value indicates high reliability of the scale.

Table 1 summarizes the responses. The survey reveals widespread agreement on how economists should choose a research topic. Intrinsic motivation is considered highly important; 85% (95% confidence interval (CI): 82–89%) agree that a topic should be chosen based on one's personal interest. Extrinsic motivation also plays an important role; 60% (CI: 55–64%) agree that the prospects for publication should be taken into account. With respect to topics for empirical research economists seem to follow a pragmatic approach; only 19% (CI: 16–23%) think that it is not acceptable to "define the research question according to data availability."

Economists clearly condemn behavior that misleads the scientific community or causes harm to careers. The least justifiable action is "copying work from others without citing." Respondents unanimously (CI: 99–100%) agree that this behavior is unjustifiable. Fabricating or correcting data as well as excluding part of the data are rejected by at least 97% (CI: 96–99%). "Using tricks to increase t-values, R^2, or other statistics" is rejected by 96% (CI: 94–98%), 93% (CI: 90–95%) consider "incorrectly giving a colleague co-authorship who has not worked on the paper" unjustifiable. Accordingly, some research norms are indeed fundamental and universal.

In the European Code of Conduct for Research Integrity (ESF and ALLEA, 2011) it is emphasized that there is a "thin borderline between some violations of [questionable research] practices and the serious types of misconduct." The survey shows that behavior typically listed as questionable are indeed only slightly more accepted. Not checking the contents of the works cited or not citing others' results if not in line with the analysis or from lower ranked journals is rejected by 86–91%. Practices such as searching for control variables until the desired result is found or selective presentation of those empirical findings that confirm one's argument are unaccepted by 81–85%. "Copying from own previous work without citing" is rejected by 80% (CI: 77–84%). Thus, it is much more accepted than plagiarism.

Strategic behavior in the publication process is also rejected but more accepted than practices applicable when analyzing data or writing papers. Citing strategically or maximizing the number of publications by slicing into the smallest publishable unit is rejected by 64% (CI: 60–69%). Complying with suggestions by referees even though one thinks they are wrong is considered unjustifiable by 61% (CI: 56–66%).

4.2. Economists' admitted own research practices

Participants were asked which research practices they had "ever" employed in the past. The responses are summarized in Table 2. Almost all economists (96%, CI: 94–97%) state that personal interest determined the choice of their research topic. The publication prospects were reported to have been decisive for 67% (CI: 62–71%).

The responses confirm the finding by List et al. (2001) that serious misbehavior exists in economics. The correction, fabrication, or partial exclusion of data, incorrect co-authorship, or copying of others' work is admitted by 1–3.5%. The use of "tricks to increase t-values, R^2, or other statistics" is reported by 7%. Having accepted or offered gifts in exchange for (co-)authorship, access to data, or promotion is admitted by 3%. Acceptance or offering of sex or money is reported by 1–2%. One percent admits to the simultaneous submission of manuscripts to journals.

About one fifth admits to having refrained from citing others' work that contradicted the own analysis or to having maximized the number of publications by slicing their work into the smallest publishable unit. Having at least once copied from their own previous work without citing is reported by 24% (CI: 20–28%). Even more admit to questionable practices of data analysis (32–38%), e.g., the "selective presentation of findings so that they confirm one's argument." Having complied with suggestions from referees despite having thought that they were wrong is reported by 39% (CI: 34–44%). Even 59% (CI: 55–64%) report that they have at least once cited strategically to increase the prospect of publishing their work.

According to their responses, 6.3% of the participants have never engaged in a practice rejected by at least a majority of peers. John et al. (2012) report almost the same fraction for psychologists. The authors find that 94% engaged in at least one questionable research practice (behavior similar to the ones considered here).

Table 2 also shows the average justifiability of research practices by respondents' own behavior. The results suggest a clear tendency of respondents who admit to a behavior to assign a higher level of justifiability to the research practice. The average difference is roughly one scale unit. John et al. (2012) report a similar difference.

4.3. Economists' reports of misbehaving colleagues

Respondents were asked which fraction of research in the top general and top field journals (A+or A) they believe to be subject to different types of misbehavior ("up to . . . %," scale given in deciles). The fabrication of data is expected to be the least widespread. The median response is "up to 10%." Respondents believe that incorrect handling of others' ideas, e.g., plagiarism, is more common; the median is "up to 20%" of published research. The "incorrect reporting of results, e.g., using tricks to improve statistics" as well

[3] Of those starting the survey, 17% left after visiting the first page (the introduction). Questions of "Part I: Norms" were answered by 56–38 dropouts.

[4] The aim was to reach economists that had not yet participated. Since follow-up surveys are only available for two countries, these data are disregarded in the analysis. Including the responses implies that about two thirds of the sample are either German or French. Results are largely unchanged when the observations are included, see Tables C.3 and C.4 of the Supplementary material (available online).

Table 1
Economists' norms.

No.	On a scale from 1 to 6...	Obs.	Ordinal variable				Binary variable			
			Mean	Std. dev.	[95% CI]		Mean	Std. dev.	[95% CI]	
	General research approach: agreement									
1	A research topic should be chosen according to one's personal interest (in contrast to career concerns)	426	2.39	1.15	2.28	2.50	0.85	0.36	0.82	0.89
2	A research topic should be chosen with respect to publication prospect	426	3.33	1.20	3.21	3.44	0.60	0.49	0.55	0.64
3	A researcher should give credit to any published and unpublished idea by someone else (i.e., colleagues, journalists, students)	424	1.80	1.27	1.68	1.92	0.88	0.32	0.85	0.91
4	Results should be generalized if the theoretical framework or the research design for empirical analysis allows for it.	420	2.44	1.13	2.33	2.54	0.84	0.37	0.81	0.88
	Research practices: justifiability									
5	Copying parts from the work of others without citing	426	1.06	0.30	1.03	1.09	1.00	0.05	0.99	1.00
6	Fabricating some data	417	1.19	0.74	1.12	1.26	0.97	0.17	0.96	0.99
7	Correcting data to fit the theory	423	1.23	0.65	1.17	1.30	0.98	0.14	0.96	0.99
8	Excluding part of the data (e.g., outliers) without reporting this	423	1.52	0.78	1.44	1.59	0.98	0.14	0.96	0.99
9	Using tricks to increase *t*-values, R^2, or other statistics	424	1.61	0.86	1.53	1.69	0.96	0.20	0.94	0.98
10	Incorrectly giving a colleague co-authorship who has not worked on the paper	425	1.83	1.04	1.73	1.93	0.93	0.26	0.90	0.95
11	Not citing results that are not in line with own analysis	426	2.01	1.17	1.90	2.12	0.89	0.31	0.86	0.92
12	Not checking the contents of the works cited	424	2.07	0.99	1.97	2.16	0.91	0.29	0.88	0.94
13	Not citing work in lower ranked journals, i.e., which in a ranking from A+to C rank lower than A	425	2.16	1.16	2.05	2.27	0.86	0.35	0.82	0.89
14	Presenting empirical findings selectively so that they confirm one's argument	424	2.19	1.17	2.08	2.30	0.84	0.37	0.81	0.88
15	Searching for control variables until you get the desired results	422	2.21	1.18	2.10	2.32	0.85	0.36	0.82	0.88
16	Stopping statistical analysis when you have a desired result	423	2.45	1.24	2.33	2.56	0.81	0.40	0.77	0.84
17	Copying from your own previous work without citing	425	2.47	1.33	2.34	2.59	0.80	0.40	0.77	0.84
18	Not citing work from other disciplines	421	2.58	1.27	2.46	2.70	0.77	0.42	0.73	0.81
19	Citing strategically to raise publication prospects (e.g., to please editors or possible referees)	426	3.00	1.31	2.87	3.12	0.64	0.48	0.60	0.69
20	Maximizing the number of publications by dividing the work into the smallest publishable units, meaning several individual articles covering similar topics and differing from each other only slightly	426	3.06	1.26	2.94	3.18	0.64	0.48	0.60	0.69
21	Complying with suggestions from referees or editors when you think they are wrong	424	3.09	1.39	2.96	3.23	0.61	0.49	0.56	0.66
22	Defining the research question according to data availability	422	4.51	1.23	4.39	4.63	0.19	0.40	0.16	0.23

The scale was given as agreement (strongly agree: 1 – strongly disagree: 6) with respect to the general research approach (items 1–4). For research practices (items 5–22) it was given as justifiability (not at all justifiable: 1 – highly justifiable: 6). Items 5–22 are listed in increasing order of justifiability. Binary variable is set to unity if respondent chose responses 1–3 of the rating scale. Based on observed data.

as "incorrect application of empirical methods, e.g., data mining" are assumed to be more prevalent. The median is "up to 30%."

Having observed at least one case of "scientific misconduct" in the department or institute is reported by 146 persons (34%, CI: 29–38%). About half of those observed only one case, two cases were observed by 18%, three cases by 6% and 22.6% report having observed more than three cases. To decrease the likelihood of duplicate reporting, respondents were asked about the cases they had observed "in their department or institute." To increase the comparability across researchers, the restriction "in the past 3 years" was given. The question did not define "scientific misconduct." Affirmative responses are based on the respondent's assessment.

Respondents that answered affirmatively were asked about the details of their observation. With regard to the type of misconduct, 18% (based on all respondents) report that the problem they had observed was unsound handling of others' ideas. Fourteen percent report that they had observed unsound application of empirical

Table 2
Economists' admitted own research behavior.

No.	Have you ever . . .	Obs.	Percent "Yes"	Std. dev.	[95% CI]		Norms by behavior		Δ	Difference significant?
							Not admitted	Admitted		
General research approach										
1	Chosen a research topic according to your personal interests	423	95.51	20.74	93.53	97.49	3.32	2.35	−0.97	***
2	Chosen a research topic with respect to publication prospect	423	66.90	47.11	62.40	71.41	3.92	3.05	−0.87	***
3	Built your research on someone else's idea without giving credit	420	1.90	13.69	0.59	3.22	1.80	1.63	−0.17	–
4	Generalized your results even though the theoretical framework or the research design for empirical analysis did not allow for it	419	13.13	33.81	9.88	16.37	2.42	2.49	0.07	–
Research practices										
5	Copied parts from work of others without citing	422	2.13	14.46	0.75	3.52	1.05	1.67	−0.62	***
6	Fabricated some data	348	2.59	15.90	0.91	4.26	1.14	3.22	−2.09	***
7	Corrected data to fit the theory	348	1.15	10.67	0.02	2.27	1.21	1.21	−0.79	***
8	Excluded part of the data (e.g., outliers) without reporting this	348	3.45	18.27	1.52	5.37	1.47	3.08	−1.62	***
9	Used tricks to increase t-value, R^2, or other statistics	348	7.18	25.86	4.46	9.91	1.52	2.64	−1.12	***
10	Failed to correctly give a colleague co-authorship who has worked on the paper	423	1.42	11.84	0.29	2.55	1.82	1.50	0.32	–
11	Refrained from citing results or opinions that are not in line with your own analysis	422	21.09	40.84	17.18	25.00	1.83	2.67	−0.85	***
12	Refrained from checking the contents of the works cited	422	51.90	50.02	47.11	56.68	1.62	2.48	−0.86	***
13	Refrained from citing work in lower ranked journals, which in a ranking from A+to C rank lower than A	421	19.95	40.01	16.12	23.79	1.94	2.94	−1.00	***
14	Presented empirical findings selectively so that they confirm one's argument	348	32.18	46.79	27.25	37.12	1.82	2.99	−1.17	***
15	Searched for control variables until you got the desired results	348	36.49	48.21	31.41	41.58	1.75	2.94	−1.20	***
16	Stopped statistical analysis when you had a desired result	348	37.93	48.59	32.81	43.05	1.94	3.23	−1.28	***
17	Copied from your own previous work without citing	423	23.64	42.54	19.58	27.71	2.18	3.37	−1.20	***
18	Refrained from citing work from other disciplines	419	19.57	39.72	15.76	23.38	2.40	3.24	−0.84	***
19	Cited strategically to raise publication prospects (e.g., to please editors or possible referees)	420	59.29	49.19	54.57	64.00	2.35	3.43	−1.08	***
20	Maximized the number of publications by dividing the work to the smallest publishable unit, meaning several individual articles covering similar topics and differing from each other only slightly	423	19.86	39.94	16.04	23.68	2.84	3.89	−1.05	***
21	Complied with suggestions by referees or editors when you thought that they are wrong	420	39.05	48.84	34.36	43.73	2.67	3.74	−1.07	***
22	Defined the research question according to data availability	345	79.13	40.70	74.82	83.44	3.90	4.72	−0.82	***
23	Submitted a manuscript simultaneously to two or more journals violating journal policies	424	1.18	10.81	0.15	2.21	–	–	–	–
24	Accepted or offered gifts in exchange for (co-)authorship, access to data or promotion of particular persons	425	3.29	17.87	1.59	4.99	–	–	–	–
25	Accepted or offered money in exchange for (co-)authorship, access to data or promotion of particular persons	424	1.41	11.82	0.28	2.54	–	–	–	–
26	Accepted or offered sex in exchange for (co-)authorship, access to data or promotion of particular persons	425	1.88	13.61	0.58	3.17	–	–	–	–

The research practices are listed in increasing order of justifiability. The number of observations is roughly 17% lower with respect to items 6–9, 14–16, and 22 as those respondents indicated that they do not work empirically. The justifiability of practices 23–26 was not inquired. Some institutions, e.g., journals or grant giving institutions, have introduced respective codes of conduct. Based on observed data.

* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

methods in their environment. Twelve percent accuse colleagues of having inappropriately presented results. Four percent report having witnessed the fabrication of data. Five percent report that the problem was incorrect co-authorship.

Fifty percent (based on affirmative responses) report that the researcher suspected of scientific misbehavior was a full professor. Compared to their fraction in the sample (27%), full professors are disproportionally often accused of misconduct. The involvement of PhD students is reported by 22%, of assistant/junior professors by 20%, of associate professors by 12%, and of post docs or researchers by 10%.

Twenty-four percent respond that they reported the suspected misconduct. Notification to the governing body of the institution is reported by 31% (based on those that made allegations). Having shared the observation with the media is reported by 25%. Twenty percent state that they took action by talking informally to other scholars about the issue. Notification to an ethics committee is reported by one respondent – supporting the view that statistics published by those institutions capture only the tip of the iceberg.

The suspicions of misbehavior are reported to have proved accurate in 62.5% of allegations. Participants report that instances of misconduct led to consequences most often when the governing body of the institution was informed (10 in 11 cases). Only 5 of the 14 cases in which colleagues were informed resulted in consequences.

Respondents indicating that they did not report the observed misconduct were asked for their reason. Thirty percent of those that refrained from allegations state that they did not know to whom they should report. Consequences for themselves were feared by 24%. For 18% the reason was loyalty towards the offender.

Respondents were asked more specifically whether they had observed certain types of misbehavior. A complaint of having been incorrectly excluded as co-author is voiced by 18%. The same fraction reports having observed others simultaneously submitting a manuscript to more than one journal, thus violating publication rules. A remarkable finding is that the majority of researchers that report having observed these behaviors respond negatively when asked whether they had observed "misconduct." While economists strongly agree on the importance of giving due credit to the contribution of others, the results may be taken as an indication that some tolerate the exploitation of their own ideas. However, as described in Section 2, the survey by Enders and Hoover (2004) shows that editors' agreement that an action constitutes the serious offense of plagiarism depends on the material that is unattributed. For example, unattributed sentences are considered less serious. The incorrect exclusion as co-author may be considered not serious enough to be classified as "misconduct."

4.4. Economists' perception of pressure

Economists were surveyed regarding their perception of the pressure to publish and to raise external funds. The respondents almost unanimously agree that publication pressure exists. Publication pressure is perceived to be "very high" by 38.9%, and "high" by 44.3%, as shown in the upper panel of Fig. 1. The lower panel of the figure shows that the perceived pressure to raise external funds is lower but still substantial. It is "very high" for 11%, "high" for 35.6%, and "moderately high" for 36.5%. Ten percent state that they do not perceive pressure to raise external funds.

Economists strongly agree that pressure has increased over the last decade, as shown in Fig. 2. A fraction of 45.5% (46.8%) believes that publication pressure (pressure to raise external funds) has "increased"; 33.7% (21.5%) even perceive a "strong increase." Constant pressure to publish (raise external funds) is reported by 7.2% (9.6%). Hardly any respondent states that pressure has decreased.

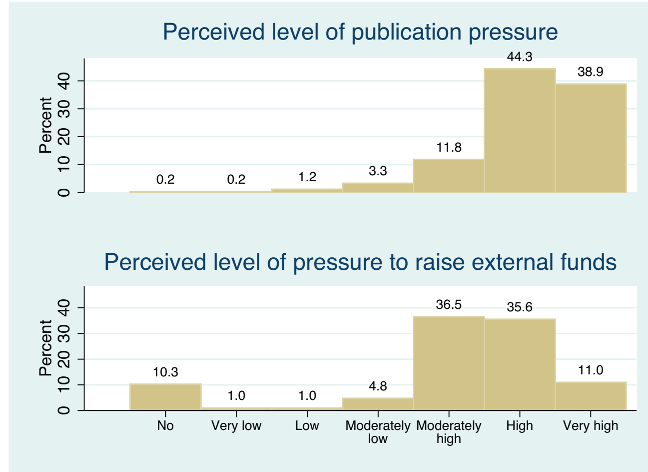

Fig. 1. Perceived level of pressure. *Note*: Based on 422/419 observations.

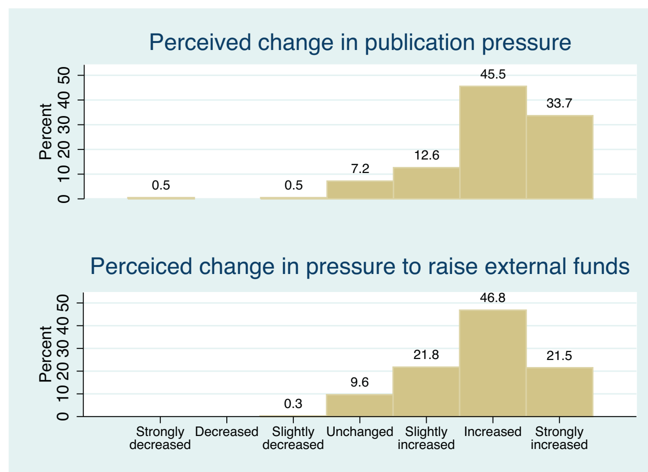

Fig. 2. Perceived change of pressure. *Note*: Based on 405/406 observations.

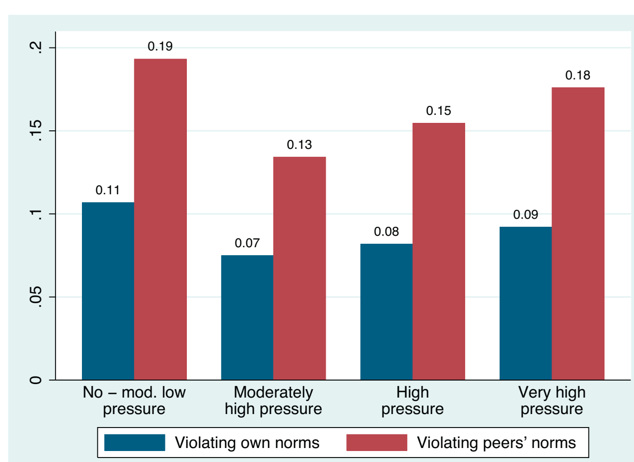

Fig. 3. Violations of research norms by perceived publication pressure. *Note*: Based on 422 observations. Violation of own norms = number of admitted misbehavior/number of rejected behavior; misbehavior classified as such if economist himself rejects the practice (responses 1–3 on a scale from 1 = not at all justifiable to 6 = highly justifiable). Violation of others' norms = same calculation; misbehavior classified as such if majority of peers reject the practice (at least 50% chose responses 1–3).

Fig. 3 plots perceived publication pressure against two variables indicating the respondent's admitted misbehavior. The first variable captures how many behavior the economist reports to have engaged in on the behavior he rejects, i.e., the violations of the economist's own convictions. The second variable captures an economist's violations of peers' research norms, i.e., engagement in practices rejected by at least 50% of participants. The figure indicates that the fraction of violated research norms is always lower if based on an economist's own convictions. The highest fraction of violations of own and others' research norms is reported by economists perceiving "no – moderately low" pressure. However, only a small fraction reports such low pressure. With regard to economists perceiving higher pressure, a positive relationship between pressure and violating research norms is indicated. The fraction of research norms (own and peers') that is reported to have been violated is slightly higher among respondents that perceive stronger pressure. With regard to peers' norms, the fractions are statistically different from each other.

5. Empirical analysis

5.1. Empirical approach

The relationship between economists' perception of pressure and scientific misbehavior is studied in an empirical analysis. Perceptions might be related to the reported research practices as well as the norms that researchers hold. In the one case, the dependent variable is the justifiability the respondent assigns to a behavior (ordinal variable, 1 = "not at all justifiable," . . ., 6 = "highly justifiable"). In the other case, admitted own research behavior is used as the dependent variable (binary variable, set to unity if the respondent reports having engaged in behavior, zero otherwise).

The models are estimated for the justifiability and own use of all research practices that are rejected by a majority (rejection rates shown in Table 1). However, low variance of the dependent variables prevents convergence of the models estimated for practices 5–10 or causes perfect prediction of several observations. These practices are summarized in one variable "(justifiability of) serious misbehavior."

The main explanatory variable is the respondent's perception of publication pressure. Being evaluated based on the scientific performance and having a tenured position are included as indirect measures of publication pressure. The economic theory of crime assumes that the decision to cheat is influenced by the expected probability of detection (Becker, 1968). The expectation of others' behavior has been found to also determine the likelihood of cheating (List et al., 2001) The regressions control for the expected probability of detection and the expected prevalence of misbehavior.

To explain the decision to cheat, economists have paid increasing attention to norms and internal rewards (e.g., Elster, 1989). Merton (1979) stresses that researchers internalize norms of science and act on them. Wilhite and Fong (2012) and John et al. (2012) report a positive link between the acceptance of a research practice and its admission. The respondent's stated view on the justifiability of a behavior is included in regressions on admitted own behavior. It is of course difficult to establish causality. Rather than behaving according to norms, people might equally well have adjusted their values to their behavior (Akerlof and Dickens, 1982).

All regressions control for the respondent's gender, year of birth, the academic position, country of workplace, and the fraction of time a researcher indicates as available for doing research. The ordinal and nominal controls are included as a set of dummies. The reference group is the highest or lowest category in case of ordered alternatives, among these the more frequent category is chosen. The reference group of unordered alternatives is the mode. Descriptions and summary statistics of all control variables are provided in Table C.1 of the online Supplementary material.

The five multiply imputed complete data sets are used separately for the analysis, the results are combined using Rubin's rule, i.e., such that they reflect the uncertainty due to the imputation.[5] The determinants cannot be said to be truly exogenous. It is impossible to make claims about the direction of causality.

5.2. Results from regressions explaining economists' norms

Table 3 provides results from ordered probit regressions on the justifiability the respondent assigns to the different unaccepted research practices. Shown are average marginal effects on the outcome "not at all justifiable." The results suggest that perceived pressure is negatively related to the justifiability of some misbehavior. The reference group is respondents perceiving "very high" pressure. Respondents perceiving less publication pressure assign higher justifiability to several research practices. For example, the probability that a respondent assesses "copying one's owns work" to be "not at all justifiable" is 2 ppts lower if he perceives "high" pressure, 7 ppts lower if he perceives "moderately high" pressure and 14 ppts lower if he perceives "no – moderately low" pressure. Most effects are statistically insignificant. Nonetheless, the result contradicts expectations.[6] However, the main hypothesis is that perceived pressure causes dishonest behavior, not a dishonest attitude.

Table 3 shows that being evaluated based on the scientific performance, i.e., having actual pressure to publish, increases the acceptance of some research practices. For example, the probability that a respondent strongly rejects "searching for control variables until the desired result is found" is 16.9 ppts lower if he is evaluated based on the scientific performance. Research norms are unrelated to having tenure.

Economists' normative convictions are significantly related to gender and year of birth (age and cohort cannot be distinguished). The probability that men find the analyzed behavior "not at all justifiable" is on average 5.7 ppts lower (results not reported, available upon request). Men have been found to respond more strongly to the competitiveness of their environment (e.g., Croson and Gneezy, 2009) and to be more likely to cheat (e.g., Friesen and Gangadharan, 2012). Fig. 4 depicts the marginal effects of year of birth in box plots. It shows that, compared to those born after 1979, economists born earlier are increasingly likely to find the listed behavior unjustifiable. Little evidence is found for cross-country differences in economists' norms (compared to Germany, i.e., the largest group, results available upon request).

5.3. Results from regressions explaining admitted research behavior

Table 4 shows average marginal effects from probit regressions on admitted own research behavior. The results suggest that the admission of several research practices is positively related to

[5] The MI estimate of β is $\overline{\beta}_M = (1/5)\sum_{i=1}^{5}\hat{\beta}_i$. The variance–covariance matrix of $\overline{\beta}_M$ is $T = \overline{U} + (1 + (1/5))B$ where $\overline{U} = \sum_{i=1}^{5}(\hat{U}_i/5)$ is the within-imputation variance–covariance matrix and $B = \sum_{i=1}^{5}((\beta_i - \overline{\beta}_M)(\beta_i - \overline{\beta}_M)^{'})/(5-1)$ is the between-imputation variance–covariance matrix. Results are largely unchanged if only observed data are used. Available upon request.

[6] To check the robustness of the finding, the set of dummies capturing perceived publication pressure is replaced by different variables, e.g., an ordinal or binary variable capturing pressure. The results point to the same conclusion as the reported ones. The modifications are described in detail in Section 5.3 with respect to admitted behavior. Results available upon request.

Table 3
Regressions on economists' norms.

Description	Dependent variable					
No. of behavior	Serious misbehavior 5–10 AME/SE	Disregard results 11 AME/SE	No check of content 12 AME/SE	Cite low ranked 13 AME/SE	Present selectively 14 AME/SE	Search controls 15 AME/SE
Perceived publication pressure...						
...no – moderately low	−0.062	−0.075	−0.231***	−0.053	−0.090	−0.204***
	(0.045)	(0.100)	(0.058)	(0.089)	(0.078)	(0.062)
...moderately high	−0.013	0.020	−0.086	−0.008	0.009	−0.104*
	(0.013)	(0.068)	(0.059)	(0.070)	(0.063)	(0.057)
...high	−0.010	0.069	0.023	0.008	0.012	0.024
	(0.007)	(0.046)	(0.047)	(0.046)	(0.042)	(0.047)
...very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Has tenured position	−0.003	−0.053	0.037	0.036	0.060	−0.012
	(0.011)	(0.074)	(0.066)	(0.066)	(0.056)	(0.063)
Scientific performance is evaluated	−0.016	−0.000	−0.050	−0.097*	−0.078	−0.169***
	(0.010)	(0.061)	(0.048)	(0.056)	(0.052)	(0.050)
Perceived probability of detection...						
...very low	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
...low	0.003	0.070	−0.013	0.035	0.042	0.030
	(0.013)	(0.065)	(0.076)	(0.075)	(0.063)	(0.072)
...moderately low	−0.006	0.052	0.015	0.014	0.021	−0.026
	(0.014)	(0.063)	(0.074)	(0.071)	(0.065)	(0.068)
...high	0.006	−0.011	0.032	0.133	0.125	0.082
	(0.014)	(0.085)	(0.090)	(0.088)	(0.084)	(0.084)
Expects high prevalence of misbehavior	−0.009	−0.009	0.027	0.047	−0.033	−0.001
	(0.007)	(0.043)	(0.041)	(0.040)	(0.037)	(0.039)
Other controls?	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	67.08	40.93	70.76	50.85	78.06	47.00
Pseudo R^2	0.04	0.03	0.05	0.04	0.06	0.04
N	426	426	426	426	426	426

Description	Dependent variable					
No. of behavior	Stop analysis 16 AME/SE	Copy own work 17 AME/SE	Cite oth. disc. 18 AME/SE	Cite strategic. 19 AME/SE	Max. publications 20 AME/SE	Comply suggestions 21 AME/SE
Perceived publication pressure...						
...no – moderately low	−0.141**	−0.142**	−0.054	−0.039	0.010	−0.040
	(0.057)	(0.064)	(0.061)	(0.045)	(0.046)	(0.047)
...moderately high	−0.014	−0.066	0.064	0.002	0.029	−0.017
	(0.052)	(0.051)	(0.057)	(0.036)	(0.032)	(0.037)
...high	0.056	−0.021	0.021	0.008	0.032	−0.012
	(0.038)	(0.040)	(0.036)	(0.027)	(0.022)	(0.024)
...very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Has tenured position	−0.028	0.009	0.008	−0.027	0.034	0.016
	(0.055)	(0.053)	(0.054)	(0.042)	(0.033)	(0.036)
Scientific performance is evaluated	−0.079*	0.042	0.015	−0.037	−0.001	−0.067**
	(0.046)	(0.051)	(0.044)	(0.031)	(0.029)	(0.031)
Perceived probability of detection...						
...very low	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
...low	0.021	0.068	−0.018	0.052	0.015	0.041
	(0.059)	(0.059)	(0.053)	(0.032)	(0.031)	(0.036)
...moderately low	−0.018	0.006	0.046	0.073**	0.045	0.025
	(0.057)	(0.058)	(0.053)	(0.032)	(0.032)	(0.034)
...high	0.084	0.066	0.059	0.151***	0.060	0.092*
	(0.073)	(0.074)	(0.068)	(0.053)	(0.042)	(0.050)
Expects high prevalence of misbehavior	−0.016	−0.075**	0.074**	0.012	−0.030	−0.021
	(0.034)	(0.035)	(0.033)	(0.024)	(0.020)	(0.023)
Other controls?	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	51.12	43.38	46.14	67.25	71.79	70.34
Pseudo R^2	0.04	0.03	0.03	0.05	0.05	0.05
N	426	426	426	426	426	426

Ordered probit estimates, reported are average marginal effects (AME) on the outcome "not at all justifiable." The variable "justifiability of serious misbehavior" assumes the value of 0 if all of the practices 5–10 are considered "not at all justifiable," the value of 1 if one of these behaviors is considered justifiable, and so on. All 5 imputations are used, results combined using Rubin's rule. Hypothesis tests based on robust standard errors. Measures of fit are the lowest statistic among results from the five imputations. (ref.), category is reference group. Other controls: location of workplace, male, year of birth, rank, fraction of research time.

* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

Table 4
Regressions on admitted research behavior.

Description	Dependent variable					
	Serious misbehavior	Disregard results	No check of content	Cite low ranked	Present selectively	Search controls
No. of behavior	5–10	11	12	13	14	15
	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE
Perceived publication pressure...						
...no – moderately low	0.017	−0.034	−0.029	0.071	−0.124	−0.080
	(0.075)	(0.089)	(0.100)	(0.100)	(0.084)	(0.100)
...moderately high	−0.056	−0.083	−0.169***	−0.127**	−0.142**	−0.083
	(0.045)	(0.054)	(0.061)	(0.052)	(0.061)	(0.076)
...high	0.035	0.012	−0.033	−0.023	−0.110**	−0.028
	(0.040)	(0.043)	(0.048)	(0.041)	(0.050)	(0.049)
...very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Has tenured position	0.042	−0.077	0.046	0.020	0.010	0.060
	(0.052)	(0.059)	(0.068)	(0.055)	(0.075)	(0.066)
Scientific performance is evaluated	0.024	−0.083	0.079	0.087	−0.010	0.028
	(0.051)	(0.052)	(0.061)	(0.061)	(0.055)	(0.059)
Perceived probability of detection...						
...very low	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
...low	0.049	0.011	0.012	0.048	−0.045	−0.108
	(0.050)	(0.070)	(0.079)	(0.053)	(0.069)	(0.085)
...moderately low	0.062	−0.047	0.031	0.096*	0.013	−0.109
	(0.054)	(0.070)	(0.080)	(0.053)	(0.070)	(0.084)
...high	−0.009	−0.145**	−0.004	0.012	−0.105	−0.078
	(0.055)	(0.074)	(0.089)	(0.064)	(0.082)	(0.101)
Expects high prevalence of misbehavior	0.124***	−0.025	−0.068	0.036	0.005	0.058
	(0.036)	(0.040)	(0.045)	(0.039)	(0.044)	(0.043)
Justifiability of practice (1 = not at all, 6 = high)	0.047***	0.092***	0.233***	0.106***	0.146***	0.183***
	(0.011)	(0.014)	(0.019)	(0.014)	(0.017)	(0.017)
Other controls?	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	56.11	60.10	121.97	77.54	101.97	92.83
Pseudo R^2	0.16	0.15	0.23	0.18	0.30	0.26
N	387	426	426	426	353	352
Description	Dependent variable					
	Stop analysis	Copy own work	Cite oth. disc.	Cite strategic.	Max. publications	Comply suggestions
No. of behavior	16	17	18	19	20	21
	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE
Perceived publication pressure...						
...no – moderately low	−0.050	0.000	−0.024	−0.125	−0.076	−0.029
	(0.119)	(0.091)	(0.084)	(0.105)	(0.079)	(0.116)
...moderately high	−0.188***	−0.048	−0.044	−0.130*	0.023	−0.036
	(0.060)	(0.054)	(0.057)	(0.069)	(0.060)	(0.067)
...high	−0.062	−0.008	0.018	−0.108**	0.006	0.021
	(0.048)	(0.041)	(0.043)	(0.047)	(0.038)	(0.048)
...very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Has tenured position	−0.040	0.072	0.058	−0.034	−0.004	−0.034
	(0.067)	(0.054)	(0.057)	(0.070)	(0.056)	(0.065)
Scientific performance is evaluated	−0.084	0.010	0.024	0.001	0.144***	0.079
	(0.059)	(0.048)	(0.051)	(0.057)	(0.054)	(0.065)
Perceived probability of detection...						
...very low	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
...low	0.009	0.041	0.090	−0.094	−0.033	−0.188**
	(0.078)	(0.061)	(0.061)	(0.074)	(0.066)	(0.083)
...moderately low	0.054	0.028	0.072	−0.138*	−0.003	−0.251***
	(0.082)	(0.061)	(0.061)	(0.074)	(0.065)	(0.083)
...high	−0.159*	0.025	−0.033	−0.184**	−0.002	−0.286***
	(0.087)	(0.072)	(0.062)	(0.091)	(0.078)	(0.095)
Expects high prevalence of misbehavior	−0.039	0.103***	0.009	0.024	0.090**	0.101**
	(0.044)	(0.037)	(0.039)	(0.045)	(0.036)	(0.044)
Justifiability of practice (1 = not at all, 6 = high)	0.172***	0.103***	0.078***	0.135***	0.105***	0.117***
	(0.015)	(0.012)	(0.014)	(0.015)	(0.014)	(0.014)
Other controls?	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	117.48	115.14	69.45	118.93	86.80	94.27
Pseudo R^2	0.32	0.24	0.15	0.25	0.22	0.18
N	353	426	426	426	426	426

Probit estimates, reported are average marginal effects (AME). The variable "serious misbehavior" is set to unity if the respondent employed at least one serious misbehavior (practices 5–10), and zero otherwise. All 5 imputations are used, results combined using Rubin's rule. Hypothesis tests based on robust standard errors. Measures of fit are the lowest statistic among results from the five imputations. (ref.), category is reference group. Other controls: location of workplace, male, year of birth, rank, fraction of research time. Number of observations lower for behavior where respondent could indicate "I do not work empirically."

* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

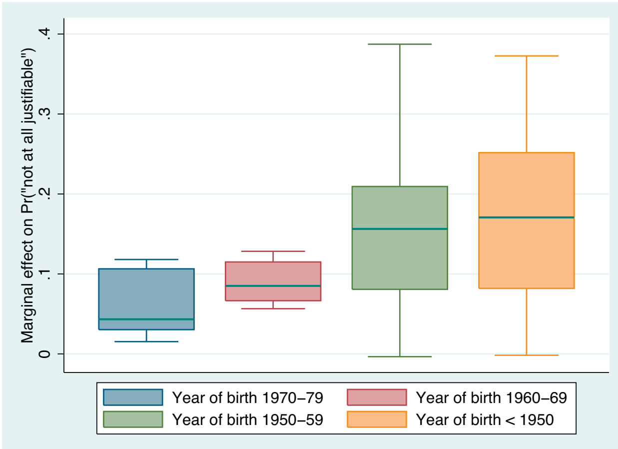

Fig. 4. Year of birth and rejection of misbehavior. *Note*: Each box plot based on 12 average marginal effects from the 12 regressions shown in Table 3. Average marginal effects on the outcome "not at all justifiable." Reference group is respondents born after 1979.

perceived publication pressure. Compared to respondents perceiving "very high" pressure, the perception of only "high" pressure implies, e.g., an 11 ppts lower probability of admitting to have "selectively presented results" or "cited strategically." The probability that respondents perceiving only "moderately high" pressure admit some behavior is even lower. For example, reporting to have "selectively presented results" is 14 ppts less likely, the effect is 17 ppts with respect to "not having checked a work's contents" and 19 ppts with respect to having "stopped the analysis when the desired result was found" (significant at 1/5% level).

The effects of lower perceived publication pressure are largely negative and of similar magnitude also with regard to other behavior. While these effects are only partially statistically significant, it has to be kept in mind that most respondents perceive some degree of high pressure (see Fig. 1). Few observations in a category, e.g., respondents perceiving "no" or "low" pressure, decrease the statistical power of the result. Results that are based on few observations are unlikely to be statistically significant. The sample sizes corresponding to each combination of perceived publication pressure and behavior are shown in Table C.2 of the Supplementary material (available online).

To check the robustness of the finding, first, the set of dummies capturing perceived publication pressure is replaced by the corresponding ordinal variable. Second, the set of dummies is replaced by a binary variable which is set to unity if the respondent perceives "very high" pressure, zero otherwise. The results, shown in Table 5, indicate again a positive association between perceived pressure and admitted misbehavior. The pattern of results resembles the one shown in Table 4.

To analyze whether the change in publication pressure over the past decade is related in a similar way to admitted misbehavior, the perception of the change is included instead of the perceived level. As shown in Table 5, the perception of a higher increase in pressure is positively related to admitting misbehavior. The effects are again only partially statistically significant. However, it has to be considered that economists agree largely also about the change of pressure (see Fig. 2). In line with previous results, a statistically significant link is found, e.g., with respect to the practices of early stopping of the empirical analysis and citing strategically.

Furthermore, the perceived pressure to raise external funds is included instead of the pressure to publish. The results, shown in Table 5, indicate a positive link also between perceived pressure to raise external funds and admitted misbehavior. However, the effects differ across practices to a larger extent and indicate a different pattern. For example, a relationship to admitting serious misbehavior is indicated which is not the case for publication pressure. Admitting strategic citation is positively related to publication pressure but not to the pressure to raise external funds.

Table 4 shows that the justifiability a respondent assigns to a behavior is clearly positively related to his admitted own behavior. A one standard deviation-increase in justifiability increases the likelihood that a respondent reports not having checked contents, having searched for control variables, or having stopped the analysis when the desired result was found by 21–23 ppts. An effect of 16–18 ppts is found with respect to the selective presentation of results, the compliance with unconvincing referee suggestions, or strategic citation. Admitting to not having cited lower-ranked journals, having maximized the number of publications, or having copied one's own work is 12–13 ppts more likely. The effect is 10–11 ppts with respect to not having cited other disciplines or results not in line with one's own analysis. The lowest relationship is found with respect to serious misbehavior (7 ppts).

In line with the results by List et al. (2001), the expectation of a high prevalence of misbehavior is significantly positively related to the admission of several practices. Results on respondents' location of workplace (not reported, available upon request) suggest that admission to misbehavior differs to some extent across countries.

6. Discussion

The survey contained several provisions to increase the accuracy of responses. Compared to other surveys of economists on the same topic, the generated response rate (17%) is in the middle of the range. While the paper-based surveys by List et al. (2001) and Enders and Hoover (2004) yielded a rate of 23 and 28% of usable responses, the web-based surveys by Enders and Hoover (2006) and Wilhite and Fong (2012) yielded a lower return (7 and 9–12% of usable responses, respectively). The response rates of web surveys have been found to be usually lower than those of other survey modes (Kaplowitz et al., 2004; Manfreda et al., 2008). However, as emphasized by Krosnick (1999), "it is not necessarily true that representativeness increases monotonically with increasing response rate. [. . .] surveys with very low response rates can be more accurate than surveys with much higher response rates."

The examination of the representativeness of the sample and the responses does not indicate systematic biases. However, this does not prove that unit non-response, self-deception, or dishonest answers do not affect the results. For questions that allow a direct comparison, self-reports are much lower than observations of others' behavior (affirmative answers: 1% versus 18%). To some extent, this may be the consequence of duplicate reporting of cases. The fraction of reported misbehavior is usually found to be much larger when it is asked about others' than about the researcher's own behavior (e.g., John et al., 2012). However, the difference may also be caused by dishonest responses or the "Muhammad Ali effect." Fanelli (2009) argues that "while surveys asking about colleagues are hard to interpret conclusively, self-reports systematically underestimate the real frequency of scientific misconduct."

In their study of questionable research practices in psychology, John et al. (2012) provide a truth-telling incentive (donation to a charity depending on the truthfulness of responses) to two-thirds of respondents. Respondents without those incentives less often admit some questionable research practices. The difference to respondents with incentives is high for falsifying data, moderate for practices such as premature stopping of data collection, and negligible for six other, more accepted practices. It would be plausible if biases were larger with respect to less accepted actions.

Respondents were asked whether they have "ever" engaged in the listed activity. Frequency of engagement was not inquired

Table 5
Regressions on admitted research behavior – modifications.

Description	Dependent variable					
	Serious misbehavior	Disregard results	No check of content	Cite low ranked	Present selectively	Search controls
No. of behavior	5–10	11	12	13	14	15
	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE
I. Perceived publication pressure as ordinal variable (no-very high)						
Ordinal publication pressure	0.006	0.021	0.042*	0.018	0.061**	0.033
	(0.020)	(0.024)	(0.025)	(0.023)	(0.025)	(0.028)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	52.01	57.92	113.13	66.76	100.20	92.73
Pseudo R^2	0.15	0.15	0.22	0.17	0.29	0.26
N	387	426	426	426	353	352
II. Perceived publication pressure binary: "very high" vs. less pressure						
Perceived publ. pressure "very high"	−0.016	0.010	0.057	0.035	0.116**	0.044
	(0.037)	(0.039)	(0.044)	(0.038)	(0.046)	(0.047)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	52.00	57.92	113.13	75.86	100.20	92.73
Pseudo R^2	0.15	0.15	0.22	0.17	0.29	0.26
N	387	426	426	426	353	352
III. Perceived change of publication pressure...						
...unchanged/decreased	−0.141***	−0.097	0.050	0.038	−0.120	−0.232***
	(0.047)	(0.066)	(0.083)	(0.082)	(0.105)	(0.088)
...slightly increased	−0.020	−0.002	−0.041	−0.086	−0.125*	−0.040
	(0.060)	(0.067)	(0.069)	(0.056)	(0.065)	(0.078)
...increased	−0.073*	−0.002	−0.013	−0.061	−0.050	−0.070
	(0.040)	(0.047)	(0.050)	(0.045)	(0.050)	(0.051)
...strongly increased	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	56.11	60.10	121.97	73.74	101.97	92.83
Pseudo R^2	0.16	0.15	0.23	0.18	0.29	0.26
N	382	425	425	425	352	351
IV. Perceived pressure to raise external funds...						
...no – moderately low	−0.169**	−0.001	0.048	0.007	−0.074	−0.009
	(0.077)	(0.082)	(0.086)	(0.071)	(0.091)	(0.089)
...moderately high	−0.123	−0.030	−0.017	0.016	−0.096	−0.017
	(0.075)	(0.075)	(0.079)	(0.065)	(0.076)	(0.076)
...high	−0.175**	−0.060	0.038	0.055	−0.056	−0.014
	(0.072)	(0.073)	(0.077)	(0.063)	(0.078)	(0.076)
...very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	62.83	59.89	111.19	67.75	101.53	95.84
Pseudo R^2	0.18	0.15	0.22	0.17	0.28	0.26
N	387	426	426	426	352	352

Description	Dependent variable					
	Stop analysis	Copy own work	Cite oth. disc.	Cite strategic.	Max. publications	Comply suggestions
No. of behavior	16	17	18	19	20	21
	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE
I. Perceived publication pressure as ordinal variable (no-very high)						
Ordinal publication pressure	0.060**	0.011	0.011	0.058**	0.009	0.010
	(0.027)	(0.023)	(0.023)	(0.026)	(0.023)	(0.028)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	113.86	112.35	66.91	114.90	85.94	90.73
Pseudo R^2	0.31	0.24	0.15	0.25	0.22	0.18
N	353	426	426	426	426	426
II. Perceived publication pressure binary: "very high" vs. less pressure						
Perceived publ. pressure "very high"	0.085*	0.016	−0.004	0.113**	−0.001	−0.006
	(0.045)	(0.038)	(0.040)	(0.044)	(0.036)	(0.045)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	113.86	112.35	47.71	114.90	36.03	90.73
Pseudo R^2	0.31	0.24	0.15	0.25	0.09	0.18
N	353	426	426	426	426	426
III. Perceived change of publication pressure						
...unchanged/decreased	−0.075	−0.116*	−0.104	−0.072	0.117	−0.060
	(0.110)	(0.067)	(0.075)	(0.089)	(0.081)	(0.086)
...slightly increased	−0.153**	−0.023	−0.100*	−0.210***	−0.019	−0.051
	(0.069)	(0.061)	(0.060)	(0.075)	(0.058)	(0.069)
...increased	−0.139***	−0.041	−0.045	−0.100**	−0.033	0.039
	(0.050)	(0.044)	(0.046)	(0.047)	(0.041)	(0.052)

Table 5 (*Continued*)

Description	Dependent variable					
	Stop analysis	Copy own work	Cite oth. disc.	Cite strategic.	Max. publications	Comply suggestions
No. of behavior	16	17	18	19	20	21
	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE	AME/SE
. . .strongly increased	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	117.48	113.26	69.15	118.93	86.80	94.27
Pseudo R^2	0.32	0.24	0.15	0.25	0.22	0.18
N	352	425	425	425	425	425
IV. Perceived pressure to raise external funds. . .						
. . .no – moderately low	−0.159**	0.003	−0.159**	−0.026	0.000	−0.194**
	(0.077)	(0.070)	(0.080)	(0.087)	(0.068)	(0.087)
. . .moderately high	−0.033	0.018	−0.093	0.008	−0.052	−0.077
	(0.067)	(0.062)	(0.072)	(0.079)	(0.059)	(0.081)
. . .high	−0.021	−0.002	−0.150**	0.095	−0.036	−0.125
	(0.067)	(0.062)	(0.070)	(0.079)	(0.056)	(0.080)
. . .very high	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)	(ref.)
Other controls as in Table 4	Yes	Yes	Yes	Yes	Yes	Yes
Chi^2	95.84	114.47	75.20	108.22	87.58	94.52
Pseudo R^2	0.31	0.22	0.17	0.22	0.23	0.19
N	352	426	426	426	426	426

Panels I: include ordinal pressure variable instead of set of dummies, higher value = higher pressure. Panels II: include binary variable that is set to unity if respondent perceives "very high" publication pressure instead of set of dummies. Panels III: include perceived change of publication pressure instead of level. Panels IV: include perceived pressure to raise external funds instead of pressure to publish. Other explanations: see notes to Table 4.

about. John et al. (2012) report that when frequency response scales are used, 64% of affirmative responses fall into the "once/twice" category, 26% fall into "occasionally," and 10% report employing practices "frequently." The authors find that frequency scales more often lead to affirmative answers than dichotomous ones. This provides another reason why self-reports are a conservative estimate of the prevalence of misbehavior.

Regarding others' behavior it was broadly asked whether respondents had observed "scientific misconduct." Respondents that did not classify colleagues' behavior as "misconduct" did not answer subsequent questions. The responses suggest that economists had serious misbehavior in mind when responding affirmatively. From that perspective, others' misbehavior may also be underreported.

To get an idea of whether economists report misbehavior more often than other researchers, the results are compared to studies from other disciplines. It has to be taken into account that the variance between studies may partly be due to different modes of delivery, objects of study (self or others), and wording (Fanelli, 2009).

Self-reports and reports on others' behavior indicate that, relative to other practices, falsification and fabrication are a rare phenomenon in economics (1–4%). At least with respect to self-reports, high consistency seems to exist across studies (List et al., 2001; John et al., 2012; Fanelli, 2009). However, the meta-analysis by Fanelli (2009), covering surveys from different disciplines, shows that on average 14.1% accuse colleagues. Scientists from the management disciplines "observed or heard about" 27% of colleagues employing data falsification (Bedeian et al., 2010).

Having engaged in questionable research practices is reported by 20–59% of economists. The prevalence of comparable practices is similar in psychology (36–78%, John et al., 2012). Between 50 and 91% of management scholars report knowledge of colleagues employing questionable research practices (Bedeian et al., 2010). The surveyed economists relatively often admit strategic behavior in the publication process (39–59%). Only 25% of management scholars report that they made revisions to conform to editors' or referees' preferences (Bedeian, 2003). Having given in to coercive citation is reported by 18% of social scientists (Wilhite and Fong, 2012).

An important question is what should and can be done to tackle scientific misbehavior in economics. Even though institutions have been established that handle allegations of scientific misbehavior, the survey reveals that half of the respondents that report having observed misconduct either did not know to whom to report or feared consequences for themselves. While complainants may not directly accrue rewards, they face costs and the potential consequences of accusing a colleague. Deficiencies in the protection of whistle blowers are, e.g., reported by Reich (2011). Hoover (2006) shows in a model that due to the low chance of success, opportunity and legal costs, fighting is unlikely to be worthwhile for the original author of a plagiarized article. As emphasized also by Hoover (2006), increasing the awareness of independent bodies that hear complaints about misbehavior and the protection for whistle blowers seem to be important steps to fight scientific misconduct.

With respect to questionable research practices, it has to be considered that the actions do not necessarily represent intentional bias. Researchers have to make several decisions while analyzing data or writing down results. Stopping the analysis when the desired result has been found may be the consequence of ambiguity about the most reliable model. Some decisions are unforeseeable and impossible to make beforehand. "Not citing work from other disciplines" may be due to carelessness rather than deliberate neglect. However, malleable categorization has been found to facilitate the re-interpretation of behavior in a self-serving manner (Mazar et al., 2008). The difference in the strength of the link between justifiability and admitted behavior found in the analysis across practices may be explained by the possibility to categorize an action in terms that are compatible with good conduct.

Glaeser (2006) proposes that "researcher initiative bias" should be accepted and results be adjusted accordingly. The strong rejection of several research practices voiced by the survey participants casts doubts on whether this is a desirable strategy. The simulations by Simmons et al. (2011) show how easily "researcher degrees of freedom" can translate into statistically significant evidence for a false hypothesis. Some research practices may be used due to a lack of awareness that they are highly rejected. Mazar et al. (2008) and Pruckner and Sausgruber (2013) show experimentally that moral reminders increase honest behavior. The prevalence of questionable practices may be limited by reminding researchers, e.g., in submission procedures, that engaging in those practices represents scientific misbehavior.

7. Conclusion

To the author's knowledge, this is the first study providing evidence for the justifiability and prevalence of a variety of research practices in economics. The survey reveals a broad consensus among professional economists about the norms that should guide researchers' behavior. The extent to which economists admit having employed unaccepted behavior is noteworthy. As in any other study of this topic, it has to be considered that the survey requested sensible information. The prevalence of misbehavior is likely to be biased – probably downward. The most frequently cited cause for scientific misbehavior is publication pressure. The surveyed economists strongly agree that high publication pressure exists. The study provides the first examination of the relationship between perceived pressure and admitting misbehavior. The results indicate that the perception of pressure is positively related to the admission of several research practices rejected by a majority of economists.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.respol.2014.05.002.

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Article

Evidence of near-ambient superconductivity in a N-doped lutetium hydride

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The absence of electrical resistance exhibited by superconducting materials would have enormous potential for applications if it existed at ambient temperature and pressure conditions. Despite decades of intense research efforts, such a state has yet to be realized[1,2]. At ambient pressures, cuprates are the material class exhibiting superconductivity to the highest critical superconducting transition temperatures (T_c), up to about 133 K (refs. [3–5]). Over the past decade, high-pressure 'chemical precompression'[6,7] of hydrogen-dominant alloys has led the search for high-temperature superconductivity, with demonstrated T_c approaching the freezing point of water in binary hydrides at megabar pressures[8–13]. Ternary hydrogen-rich compounds, such as carbonaceous sulfur hydride, offer an even larger chemical space to potentially improve the properties of superconducting hydrides[14–21]. Here we report evidence of superconductivity on a nitrogen-doped lutetium hydride with a maximum T_c of 294 K at 10 kbar, that is, superconductivity at room temperature and near-ambient pressures. The compound was synthesized under high-pressure high-temperature conditions and then—after full recoverability—its material and superconducting properties were examined along compression pathways. These include temperature-dependent resistance with and without an applied magnetic field, the magnetization (M) versus magnetic field (H) curve, a.c. and d.c. magnetic susceptibility, as well as heat-capacity measurements. X-ray diffraction (XRD), energy-dispersive X-ray (EDX) and theoretical simulations provide some insight into the stoichiometry of the synthesized material. Nevertheless, further experiments and simulations are needed to determine the exact stoichiometry of hydrogen and nitrogen, and their respective atomistic positions, in a greater effort to further understand the superconducting state of the material.

Dense elemental hydrogen has long been predicted to be a very-high-temperature superconductor[22,23], yet the extremely high pressures required have presented challenges in confirming those superconducting phases[24,25]. The superhydride materials offer the promise of retaining the superconducting properties of dense elemental hydrogen but at much lower pressures. The prediction of a 220–235-K superconducting transition temperature (T_c) in CaH_6 at 150 GPa (ref. [26]) and the watershed discovery of a 203-K T_c for H_3S at 155 GPa (ref. [27]) have instigated a materials discovery boon in which, at present, almost all possible binary systems of high-pressure hydride systems have been modelled[28]. The recent observation of an anomalously high T_c in YH_6 showed that high-temperature superconductivity can be achieved with lower hydrogen content and more modest pressures than previously understood[13]. As the main discoveries have all been at greater than megabar pressures, the goal has shifted to further lowering the pressure required, with a focus on the vast sample space of ternary hydride compounds. One direction is a third, light element acting as a dopant in the metal hydrides, which is predicted to have two main beneficial effects[29]. First, there is a predicted increase in T_c as seen in proposed examples such as critical temperatures approaching 500 K in the Li–Mg–H system, although still in the megabar regime[17], and virtual crystal approximation simulations and recent experimental evidence indicating an increase of the transition temperature by at least 25 K from doping the LaH_{10} framework[18,19,30]. Second, the addition of a third element can greatly enhance the stability of a hydrogen-rich lattice, thereby lowering the pressure range over which it is stable. $LaBH_8$ is predicted to be stable down to 20–40 GPa while maintaining its high-temperature superconductivity[20,21], and a metal–boron–carbon clathrate is predicted to retain its superconducting properties at ambient pressures[31]. The presence of stability combined with increasing T_c by introducing the third element opens the possibility of pushing the hydride superconductors to higher values of T_c at sub-megabar pressures.

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As there is an overwhelming amount of phase space unexplored by simulation in ternary rare-earth hydrides, rational chemical design is needed at present to identify the next candidate material. The La and Y binary superhydrides are predicted and measured to adopt similar high-pressure stoichiometries and phases with the Y-based ones exhibiting higher T_c at equivalent pressures[8–10,12]. The smaller size of the Y^{3+} cation offers a simple chemical rationale for this behaviour. However, the Sc hydrides with an even smaller ionic radius are predicted to have completely different structures and lower T_c (ref. [32]). Owing to the lanthanoid contraction, the lanthanoids heavier than Dy offer comparable or smaller trivalent ionic radii than Y but with the complication of *f* electrons[33–35]. Although the 4*f* electrons in lanthanoid compounds are often atom-localized and semivalent at ambient conditions, the inherent magnetism of partially occupied 4*f* states[36–38] or migration towards the Fermi level under pressure could be detrimental to the superconducting properties[9,39]. Although synthesis efforts for the high-pressure YbH_x system have produced structures distinct from its La and Y counterparts, probably owing to the transfer of *d* electrons to unoccupied *f* states[40], predictions indicate that hydrides of the two heaviest lanthanoids should be able to achieve $T_c \geq 145$ K by a megabar owing to the strong electron correlation of the 4*f* electrons near the Fermi level[41]. Causes of the high T_c achieved in the sub-megabar regime are believed to be twofold. First, the over half-filled valence 4*f* states suppress the phonon softening and second they provide some enhancement to the electron–phonon coupling relative to the transition metal (Y and La) rare earths. Combining the benefits of light atom doping and the presence of 4*f* electrons in the valance states should increase the stability of a hydrogen-rich rare-earth hydride to lower pressures while potentially enhancing its superconducting properties.

In this paper, we present experimental evidence of superconductivity at 294 K and 10 kbar pressure in a ternary lutetium–nitrogen–hydrogen compound in which the combination of a full 4*f* shell along with the electron donation and chemical pressure of the nitrogen drive the T_c and pressure stability of nitrogen-doped lutetium hydride into the near-ambient regime. The measured superconducting properties are the observation of zero resistance, a.c. magnetic susceptibility and d.c. magnetic susceptibility with zero field and field cooling, magnetization *M*–*H* curve, heat capacity, voltage–current (*V*–*I*) curves and the reduction of T_c under an external magnetic field with an upper critical magnetic field of about 88 tesla based on the Ginzburg–Landau (GL) model at zero temperature (see Extended Data Fig. 15). The composition and structure are explored with elemental analysis, EDX measurements, XRD, Raman spectroscopy and density functional theory (DFT) simulations.

Temperature–pressure relations and visual change

The near-ambient superconducting stability regime of the ternary lutetium–nitrogen–hydrogen system extends from about 3 kbar to about 30 kbar (Fig. 1a) and is accompanied by a marked visual transformation over just a few kbar of pressure (Fig. 1b). The recovered sample is initially in a non-superconducting metallic phase with a lustrous bluish colour, denoted here as phase I. Compression to about 3 kbar drives the progression of the system into phase II, leading to the onset of the superconducting regime, and this transformation is associated with a sudden change in colour from blue to pink. T_c as determined by electrical-resistance, magnetic-susceptibility and heat capacity-measurements increases with pressure from 171 K at around 5 kbar until it peaks at 294 K at around 10 kbar. The 10-kbar turning point in the superconducting dome is followed by a reduction in T_c to approximately 200 K before about 30 kbar. Compression above the highest pressure T_c shown in Fig. 1a drives the sample through another phase transition into phase III. Phase III is a non-superconducting metallic state that is once again distinct in colour, being bright red in appearance. The colour changes are for reflected light only and the sample is completely opaque for transmitted light.

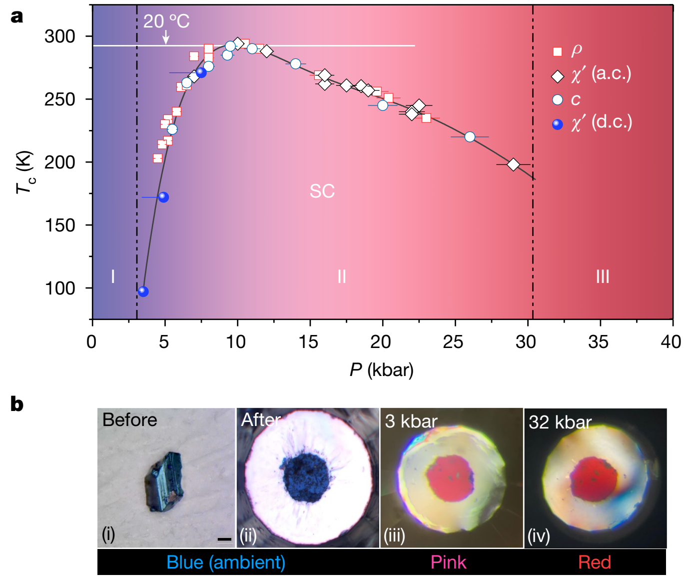

Fig. 1 | Superconductivity in lutetium–nitrogen–hydrogen at near-ambient pressures. a, Evolution of the superconducting transition temperature (T_c) of recompressed nitrogen-doped lutetium hydride as a function of pressure (*P*), illustrating a clear dome-shaped peak around 10 kbar with a T_c of 294 K. Superconductivity (SC) is only observed in phase II between about 3 kbar and about 30 kbar of pressure. ρ, electrical resistance; χ′ (a.c.), dynamic magnetic susceptibility; χ′ (d.c), static magnetic susceptibility; *c*, heat capacity. **b**, Microphotographs of a sample using only reflected light recovered from a metallic sample from high-pressure high-temperature synthesis before being loaded into the diamond anvil cell (i) and after loading at ambient pressure, showing a remarkable blue colour (ii). Scale bar, 10 µm. The sample is completely opaque to transmitted light. Under pressure, the sample transformed from blue to pink at about 3 kbar (iii) and to red at about 30 kbar (iv).

Temperature-dependent electrical resistance

The superconducting transitions of phase II are evidenced by a sharp drop in resistance within a temperature change of a few degrees kelvin (Fig. 2a). The temperature-dependent resistance data were acquired during the natural warming cycle (about 0.25 K min^{-1}) with a current of 100 µA to 2 mA. The accuracy of the temperature probe is ±0.1 K and the transition temperature was determined from the onset of superconductivity. In all experiments, the reported pressure was measured using ruby fluorescence. The transition width in zero applied magnetic field, as observed in other high-T_c hydride systems, has a $\Delta T/T_c$ value ranging from 0.005 to 0.036, and such features are readily explained within the dirty limit as described by GL theory[42]. The *V*–*I* relations are simultaneously measured along with the four-probe electrical-resistance measurements. Figure 2b shows the *V*–*I* characteristics with steadily increasing current measured in zero applied magnetic field. At a temperature above the superconducting transition ($T = 297$ K > $T_c = 294$ K), a linear *V*–*I* response following Ohm's law was observed for the metallic state of nitrogen-doped lutetium hydride at 10 kbar. As the temperature is reduced below T_c ($T = 30$ K) at the same pressure, the voltage drop is immeasurably low (essentially zero) and shows a nonlinear, $V \propto I^{3(2.84)}$ response. The *V*–*I* data were obtained from the *V*, *I* pair, shown in Fig. 2b.

Magnetic susceptibility

Another key criterion for a superconducting material is the demonstration of the Meissner effect. In a type I superconductor, this should—in principle—equate to perfect diamagnetism below the critical field, whereas in a type II superconductor, there exists perfect diamagnetism below the lower critical field and a vortex state between the upper

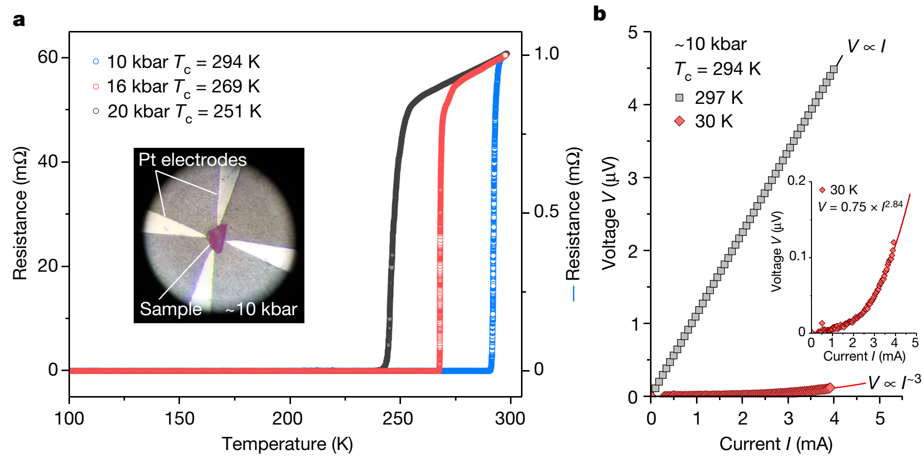

Fig. 2 | Temperature-dependent and field-dependent electrical resistance and *V*–*I* behaviour of the lutetium–nitrogen–hydrogen system. **a**, Temperature-dependent electrical resistance of nitrogen-doped lutetium hydride at high pressures, showing the superconducting transitions as high as 294 K at 10 ± 0.1 kbar, the highest transition temperature measured in all experimental runs. The colours represent the transition at different pressures. The right *y* axis represents the 10-kbar resistance versus temperature in blue colour for a different pair of *V* and *I* contacts. The data were obtained during the warming cycle to minimize the electronic and cooling noise. The inset illustrates the experimental setup for the electrical resistance at around 10 kbar using platinum (Pt) metal probes in a four-probe configuration. **b**, *V*–*I* characteristics measured at temperatures of 297 K and 30 K at 10 kbar. The transition temperature (T_c) is 294 K and above that temperature, the sample exhibits typical linear behaviour. Below T_c (T = 294 K), well within the superconducting regime, at the same pressure, a nonlinear, $V \propto I^{3(2.84)}$ response is shown. The inset highlights the power law *V*–*I* dependence.

and lower critical fields. The temperature dependence of the magnetic moments and *M*–*H* curves at different temperatures were measured on a Quantum Design Physical Property Measurement System (PPMS) by using the Vibrating Sample Magnetometer (VSM) method. Figure 3a shows the d.c. magnetic susceptibility ($\chi = M/H$, in which M is magnetization and H is magnetic field) as a function of temperature, under conditions of zero field cooling (ZFC) and field cooling (FC) at 60 Oe. The existence of the superconducting phase was then confirmed by measuring the Meissner effect on cooling in a magnetic field. The onset of a well-defined Meissner effect was observed at about 277 K at around 8 kbar. The *M*–*H* data were recorded using a PPMS with VSM option (see Fig. 3b). We used an HMD high-pressure cell and Daphne oil as the medium for applying pressure. Compared with a diamond anvil cell (DAC), the maximum pressure achievable is considerably lower in a HMD high-pressure cell. The HMD high-pressure cell is rated to reach a maximum pressure of 13 kbar, although we have not been able to achieve such a pressure. Because the filling factor of the sample is small (limited by the synthesis procedure), achieving the rated 10 kbar will require substantially greater pressure-cell compression. The maximum pressure we were able to generate was about 8 kbar. The pressure dependence of T_c is approximately 30 K kbar^{-1} from about 3 kbar to about 10 kbar. The broad transition is most probably because of the pressure gradient caused by the high-pressure cell and/or by chemical inhomogeneities in the main sample. The temperatures observed for the onset of diamagnetism with ZFC are commensurate with those from the electrical-resistance measurements.

The diamagnetic response of nitrogen-doped lutetium hydride is also seen by a 30–50-nV drop in the real part of temperature-dependent a.c. susceptibility, $\chi'(T)$, for different pressures across the superconducting stability range of phase II (Fig. 3c). The techniques for measuring a.c. susceptibility were similar to those of Snider et al.[14,15] and with respect to background subtraction; here we have used a cubic polynomial (see Extended Data Fig. 5). Given that the trivalent rare-earth elements are extremely reactive, the synthesis can be tricky and, consequently, the amount of superconducting sample can vary and thus the strength of the signal is dependent on volume. On average, sample sizes are on the order of 70–100 µm in diameter and 10–20 µm thick. For larger samples, the strength of the diamagnetic response increases by nearly five times in magnitude (see Extended Data Fig. 6). The transition width (ΔT_c), as observed in other high-T_c hydride systems, has a value of approximately 0.8 K, 2 K and 5 K at T_c of 294 K (at 10 kbar), 269 K (16 kbar) and 238 K (22 kbar), respectively, indicating the pressure broadening. Extended Data Fig. 12 shows the a.c. susceptibility, with the electrical resistance showing similar critical temperatures and very similar transition widths.

a.c. calorimetry of lutetium–nitrogen–hydrogen

The specific heat (C) is an important thermodynamic quantity and is extensively used at ambient pressures to confirm bulk superconductivity. The BCS model superconductors have an energy gap associated with the formation of Cooper pairs, resulting in a spike in the specific heat of a superconductor at T_c. However, detecting such heat anomalies at high pressure is difficult because of the highly thermally conductive environment of the diamonds. In this study, we have used a new setup of the a.c. calorimetric technique for measuring the specific heat[43]. The sample is thermally excited by an a.c. applied at frequency $\omega/2$ to a resistance heater, leading to an a.c. heat power at frequency ω to determine the specific heat capacity (C) of the sample (see Methods for more information). Using the well-known superconducting transition in MgB_2 as a test case (Extended Data Fig. 4), we find that the higher-frequency value on the falling edge of the plateau provides the cleanest response for measurements. A frequency sweep above T_c easily identifies the falling edge of the plateau, and the resultant heat capacity of MgB_2 at 15 kbar shows the distinctive discontinuity of the specific heat capacity at 32 K. Replicating this procedure in the superconducting stability regime of phase II yields specific-heat-capacity curves exhibiting the distinctive discontinuity (Fig. 4a–c). The T_c values identified in this manner are very similar to those found through both electrical resistance and a.c. susceptibility, identifying a bulk nature for the transition and the shape of the superconducting dome shown in Fig. 1a. The highest T_c we have observed using this method is 292 K at about 10 kbar. These measurements are also subject to a sample-size dependency, and the typical samples here are about 60–100 µm in diameter.

Composition and structure

The composition of the superconducting ternary lutetium–nitrogen–hydrogen compound was identified by using a combination of

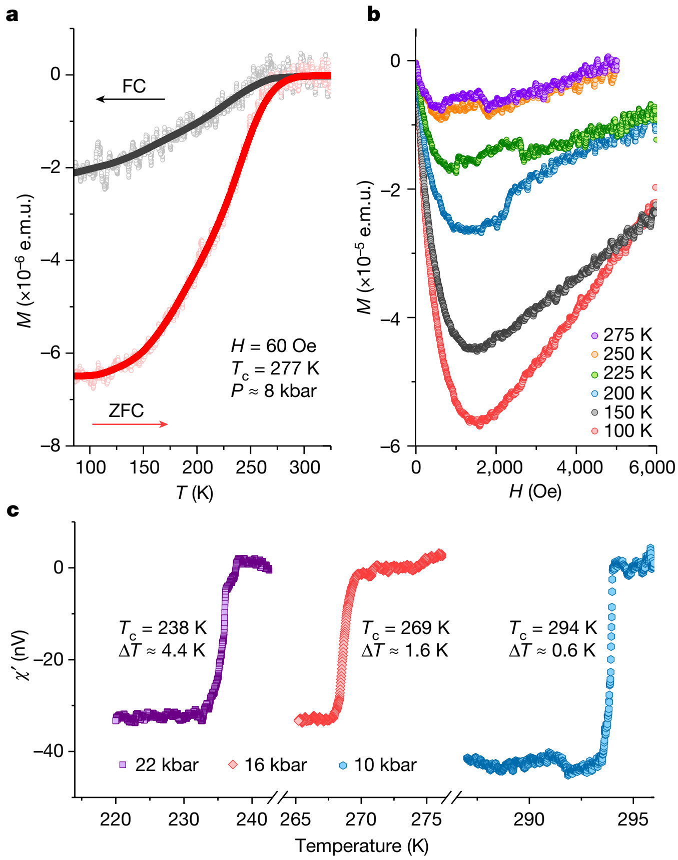

Fig. 3 | Magnetic susceptibility. a, Magnetic susceptibility ($\chi = M/H$, in which M is magnetization and H is magnetic field) as a function of temperature (T) under conditions of zero field cooling (ZFC) and field cooling (FC) at a d.c. field of 60 Oe. **b**, M–H curves recorded close to zero field. **c**, a.c. susceptibility (χ) in nanovolts versus temperature at select pressures, showing marked diamagnetic shielding of the superconducting transition for pressures of 10–22 kbar. The superconducting transition shifts rapidly under pressure to lower temperatures. T_c is determined from the temperature at the onset of the transition. A cubic or quadratic fit of the background signal has been subtracted from the data. We have applied a ten-point adjacent average smoothing for all d.c. magnetization data.

elemental analysis and EDX analysis on the synthesized sample at ambient pressures. The bulk material consistently shows the presence of nitrogen with an average weight percent of 0.8–0.9%N using elemental analysis. EDX, although qualitative, provides evidence of nitrogen in various domains of the overall sample, which we related to partial inhomogeneity in our samples (see Extended Data Fig. 7). The atomic arrangement of these elements is the crux of why the material superconducts, and both XRD and Raman spectroscopy (see Extended Data Fig. 1) show the presence of two distinct hydride compounds in nearly all samples. Both compounds have the same chemical construct of a face-centred cubic (fcc) metal sublattice but with varying contents of hydrogen and nitrogen and a distinct difference in colour. Compound A is indexed as $Fm\bar{3}m$ with a lattice constant of a = 5.0289(4) Å, whereas compound B has a = 4.7529(9) Å, both of which are indicative of lanthanoid hydride and nitride compounds, respectively[9,35,41,44] (Fig. 5a). The mononitride of lutetium is known and reported to adopt a rock-salt (RS) structure with a lattice constant of a = 4.76 Å (ref. [44]), very similar to what is measured here for compound B. DFT optimization of the RS and a hypothetical zincblende (ZB) mononitride yields a = 4.767 and 5.144 Å, respectively. In the same lattices, the hypothetical RS and ZB structure Lu monohydrides have DFT-optimized lattice constants of a = 4.800 and 5.027 Å, respectively. Altering the H and N concentration in the RS structure causes the lattice constant to vary between the limits set by the two parent compounds. Forming fully stoichiometric monohydrides and mononitrides is known to be difficult, so compound B is tentatively assigned as the RS mononitride with potential hydrogen substitution/intercalation, that is, $LuN_{1-\delta}H_{\varepsilon}$.

The electronic and structural evolutions of compound A are codependent and evolve synchronously. Raman spectroscopy of the starting material shows a linear-like progression with compression as modes harden associated with bond stiffening. A gradient change in the mode progression is observed above 3 kbar, in step with the onset of superconductivity in phase II (see Extended Data Fig. 1). There is no registered change in the indexed $Fm\bar{3}m$ symmetry as the phase I to phase II boundary is crossed, indicative of an isostructural second-order phase transition, at least in relation to the cation positions. Compressing phase II into non-superconducting phase III is a first-order structural phase transition with a roughly 0.3% volume discontinuity and a reduction in symmetry of the metal sublattice to the orthorhombic $Immm$ space group. Diminishing quantum properties as the loss of the superconductivity can be associated with a sudden increase in the degrees of freedom associated with phonon propagation through the lattice, yet there is no pronounced change in the Raman spectra other than the expected hardening of modes with compression and the disappearance of one of the low-frequency modes.

At ambient, the dihydride is a blue compound that takes on the fluorite structure (CaF_2, a fcc metal sublattice and the hydrogens almost entirely occupying the tetrahedral interstices), with a lattice constant of 5.033 Å (refs. [45–48]). Although 5.033 Å is larger than what is measured here for compound A, the lanthanoid dihydrides including Lu form solid solutions, LnH_{2+x}, that contract the lattice with further hydrogen uptake[45,46,49,50]. The presence of impurities such as O or N enables LuH_{2+x} to take on extra hydrogen compared with purer metal samples, although that contraction is only 10% that of other Ln hydrides and not enough to explain the lattice constant observed for phase I of compound A (refs. [49,50]). The ambient trihydride adopts a hexagonal $P\bar{3}c1$ phase[51]; however, a cubic trihydride phase begins to form under compression around 12 GPa and is recoverable to ambient[52]. DFT optimizations of the cubic Lu dihydride and trihydride give a = 5.025 and 5.012 Å, respectively, and an alternative higher-energy model of the dihydride with 50% of the hydrogens occupying all the octahedral sites and the other 50% occupying the tetrahedral interstices as in the ZB structure gives a = 4.960 Å. The disagreement between the computed and experimental lattice constant for the dihydride allows an estimate for the error in the DFT lattice predictions, but—more importantly—the difference in the computed lattice constants corroborates the expected lattice contraction on increasing hydrogen content from the dihydride to the trihydride. We interpret the ZB monohydride structure having a nearly identical lattice constant to the dihydride to mean that little change in the lattice should be anticipated when occupying further tetrahedral interstices with H beyond the ZB structure. For N incorporation into the lattice, as opposed to in grain boundaries as in the studies on further H uptake in the dihydride[49,50], DFT predicts a = 4.949 Å for adding a single N at an octahedral interstice in the cubic dihydride lattice, $LuH_2N_{0.25}$, and a = 5.034 Å for complete N occupation of the octahedral sites, LuH_2N. In the cubic-trihydride structure, replacing a single H for a N gives a = 5.028 and 5.146 Å for octahedral and tetrahedral interstices, respectively, which reduces to a = 5.021 and 5.080 Å, respectively, if the single N replacement is in a 2 × 2 × 2 supercell of the primitive rhombohedral cell.

In the harmonic approximation, the dihydride is the only stoichiometric low-H cubic Lu hydride found to be dynamically stable at ambient pressure (see Extended Data Fig. 8). The temperature-dependent conductivity of ambient-pressure LuH_{2+x} is known[49,50,53] and electron–phonon calculations corroborate 0-kbar LuH_2 as non-superconducting with low values of λ = 0.189 and ω_{log} = 363 K. ZB LuH has a weak instability, with the acoustic phonons at X precluding a calculation of its

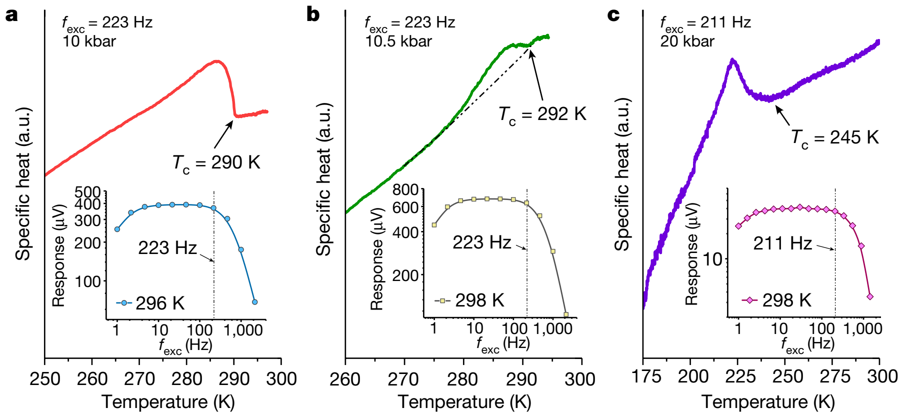

Fig. 4 | Specific-heat-capacity measurement on the superconducting lutetium–nitrogen–hydrogen system. a–**c**, Specific heat capacity of nitrogen-doped lutetium hydride at 10 kbar (**a**), 10.5 kbar (**b**) and 20 kbar (**c**), showing the superconducting transition as high as 292 K at 10.5 kbar in **b**. The drive frequency (f_{exc}) and frequency sweeps of each measurement are depicted in the insets. The strength of the heat-capacity anomaly associated with superconductivity varied owing to volume fraction as shown in **c**. The dashed line is a guide to the eye to distinguish the trend of the heat-capacity anomaly before and after the transition.

electron–phonon properties without a treatment for anharmonicity, but—because of the similarity between its and LuH_2's phonon band structure—we do not believe it to be a strong candidate for compound A. The larger harmonic dynamic instability at Γ in LuH_3 is a T_{1u} optical phonon mode that splits, with one branch becoming more unstable in other parts of the Brillouin zone. As this lattice could potentially be metastably recovered to ambient conditions[52,54], the stabilization of the material could also be attributed to anharmonic effects. Simulated compression to 15 GPa, at which LuH_3 has been observed experimentally, quenches the harmonic instabilities at the zone centre but not away from it, further indicating that anharmonicity plays a role in stabilizing cubic LuH_3 against the harmonic instabilities of the optical modes. An optical phonon mode of RS LuH also exhibits large harmonic dynamic instabilities, indicating that unstable optical modes arise from hydrogens in the octahedral fcc interstices. This observation is in line with neutron-diffraction results for cubic $NdD_{2.61}$, in which the D in the octahedral site shifts away from the 4b Wyckoff site to a partially occupied, lower-symmetry 32f site[55].

Single N substitution in the cubic cell of LuH_3 at both types of interstitial site increases the (harmonic) dynamic instability at Γ; however, they both split the highly degenerate zone-centred phonon modes of LuH_3, making more of them Raman active, in line with what is observed experimentally. Substitution at the tetrahedral site was found to be more enthalpically favourable than at the octahedral site (not vibrationally corrected), whereas Rietveld refinements provided similar patterns for N substitution at either site (see Extended Data Fig. 9). The LuH_2 to LuH_3 transformation is a metal to semimetal transition, wherein the Lu *d* electron driving the metallicity in LuH_2 donates to/interacts with the octahedral hydrogens in LuH_3, leading to a van Hove singularity[56] just below the Fermi level (see Extended Data Fig. 10). N incorporation at an octahedral interstice sees an increase in metallic character versus LuH_3, with the N p states being metallic, as well as an increased density of H states at the Fermi level. Conversely, N incorporation at a tetrahedral interstice drives the system into a semiconducting state. Although N is more electronegative than H, it does not go to N^{3-} in either case as N p states are in the conduction band, implying *M*–*N* covalencies. Also, N being more electronegative will prevent the formation of only H^- anions in the lattice, and H^- anions are known to be unfavourable for superconductivity. The primary reason for the difference in the electronic behaviours of the two types of substitution is that octahedral substitution has a minimal impact on the parent lattice, whereas tetrahedral substitution pushes the octahedral hydrogens into the opposite octant of the cube, similar to the packing seen in $LaBH_8$ (refs. [21,57,58]) (see Extended Data Fig. 11), which—in turn—leads to disordering of the Lu atoms and an approximately 0.12-Å expansion of the lattice distortions, well beyond what is measured by XRD. A lower N content suppresses the magnitude of the distortions seen for the tetrahedral substitution, and likewise its deviation away from metallicity, but not to the extent to provide a better match with experimental results as compared with octahedral substitution.

Preliminary investigations into adding H-vacancy defects into the cubic cell of the trihydride structure show that, as with the introduction of N, there is a varied response to the lattice, with the removal of an octahedral H giving a = 5.007 Å and the removal of a tetrahedral H giving a = 5.065 Å. These models both reduce in magnitude but do not remove the optical harmonic dynamic instability at Γ. As with N substitution, these structures split the phonon modes of the parent lattice at Γ, making many of them Raman active, such as what is observed experimentally. Considering that the ground-state structure of several of the ambient rare-earth trihydrides are hexagonal lattices, yet surface defects can metastably trap the high-pressure cubic phase down to ambient conditions as with YH_3 (ref. [54]), the anharmonicity of the hydrogenic phonons[59] along with a combination of N substitutions and H-vacancy defects are probably promoting the formation of a superconducting nitrogen-doped lutetium hydride with higher H content than the dihydride.

Discussion

Clearly, state-of-the-art experiments are needed to determine the exact crystal structure and stoichiometry of nitrogen-doped lutetium hydride and similar materials showing such high-temperature superconducting states. The use of techniques such as neutron diffraction and X-ray spectroscopy, as supported by simulations, are the most likely to provide a route to directly investigating the light elemental content of doped-metal hydrides and to build reliable atomistic descriptions of their chemical environments. A better detailed structural descriptor will enable theoretical modelling of these non-stoichiometric metal hydrides and improved theoretical understanding. An important distinction to make is that XRD was not satisfactorily authoritative for these hydrides even at ambient conditions, a shortcoming of such a technique that we have already highlighted in our work on carbonaceous sulfur hydride[14–16]. The fact that, in this study, we experience a lack of accuracy at ambient conditions confirms our concerns of using XRD techniques for determining hydrogen stoichiometry at more extreme conditions. The inability to accurately measure defect

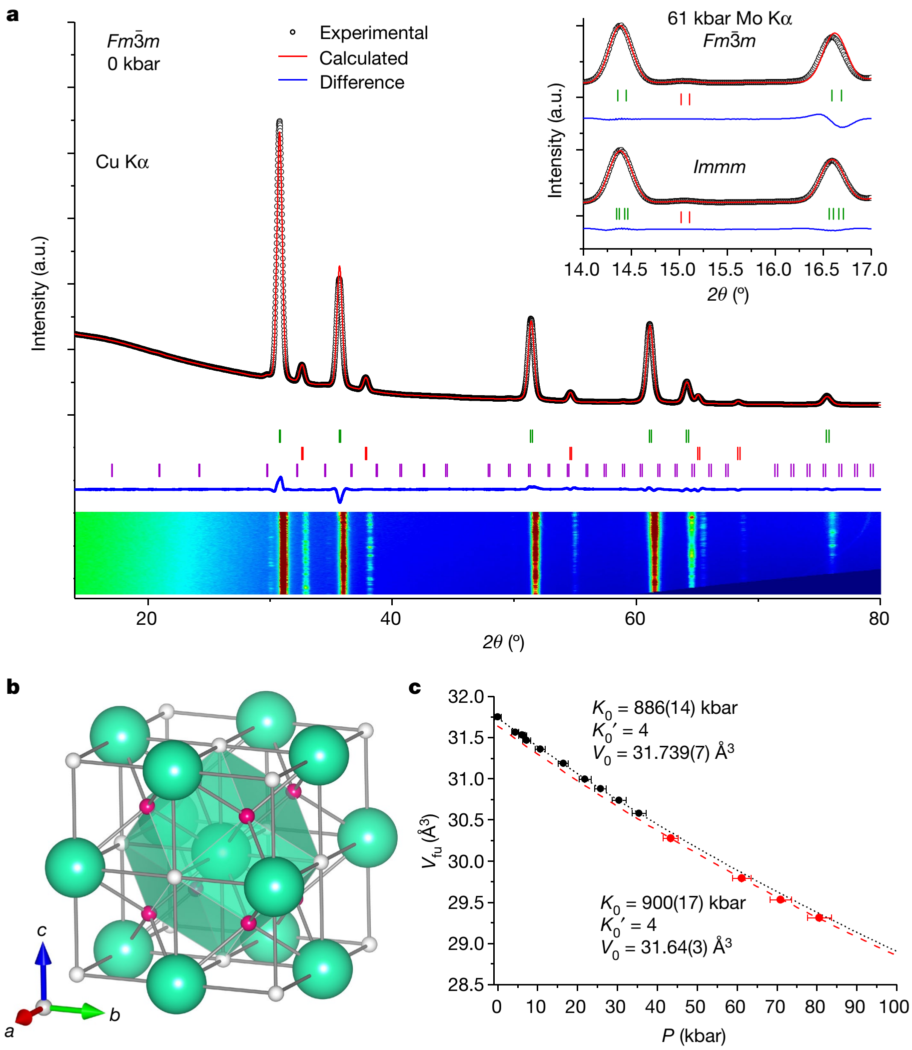

Fig. 5 | XRD studies of the superconducting lutetium–nitrogen–hydrogen system. a, Rietveld refinement of the X-ray powder diffraction data collected at 295 K with Cu Kα radiation. The black points, red line and blue line represent the observed data, calculated intensity and the difference between observed and calculated intensities, respectively. Green tick marks represent the expected Bragg peak positions for the main phase, which is probably $LuH_{3-\delta}N_{\varepsilon}$ (92.25%); minor phases, which are probably $LuN_{1-\delta}H_{\varepsilon}$ (7.29%) and Lu_2O_3 (0.46%), are shown as red and purple tick marks, respectively. The colour map is a cake representation of the X-ray powder diffraction data at ambient pressure. Insets show Le Bail fitting of high-pressure powder diffraction data at 61 kbar with the *Fm*3̄*m* and *Immm* space groups. **b**, The crystal structure of the proposed $LuH_{3-\delta}N_{\varepsilon}$ phase. The hydrogens in octahedral interstitial sites are shown in white and those in tetrahedral interstitial sites are in pink. The lutetium atoms are in green and the coordination polyhedron is shown about the central Lu atom. The cell is shifted by (0.5, 0.5, 0.5) fractional coordinates from the standard setting to better represent the coordination polyhedron. **c**, The lattice constant as a function of pressure for the *Fm*3̄*m* main phase. The Le Bail method was used for the refinement of the high-pressure XRD data. The equation of state was fitted using the Birch–Murnaghan method, as shown by the dashed lines for two pressure ranges, 0 kbar < P < 40 kbar (black) and P > 42.7 kbar (red), and the corresponding K_0 (bulk modulus at P = 0), V_0 (reference volume at P = 0) and K_0' (derivative of the bulk modulus with respect to pressure at P = 0) are shown.

densities and fractional occupancies of the lightest elements is mostly a consequence of extremely complex synthesis techniques and which in turn limits the accurate boundary conditions to aid theoretical methods for modelling and predicting the quantum properties of such materials. In summary, the most remarkable result of this study is the evidence for the near-ambient superconducting state observed in N-doped lutetium hydride with T_c of 294 K at 10 kbar. On the basis of the measured XRD and Raman spectra, the observed superconducting properties can most probably be attributed to *Fm*3̄*m* $LuH_{3-\delta}N_{\varepsilon}$, for which different non-stoichiometric values are used to indicate the possibility of both N-substitution and H-vacancy defects. The physical properties of the superconducting N-doped lutetium hydride will be better constrained by magnetic-field-dependence resistance, susceptibility and heat-capacity measurements. Whilst all other high-temperature superconducting metal hydrides have been observed at multi-megabar pressure conditions, our discovery of a 21 °C superconducting material at 10 kbar will certainly lead to the emergence of a new field of materials science, as such conditions are substantially more accessible to a multitude of new researchers outside the field of high-pressure physics.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-023-05742-0.

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Methods

High-pressure experiments

This study was based on a large number of experiments, with more than a hundred samples. The samples were loaded onto a membrane-driven diamond anvil cell (m-DAC), using 1/3-carat, type Ia diamond anvils with a 0.2-mm, 0.4-mm, 0.6-mm and 0.8-mm (for low pressures) culet. A 0.25-mm-thick rhenium gasket was pre-indented to 15–100 μm (depending on the pressure and experiment) and a 120-μm hole (or 280 μm or 600 μm for low pressures) was electrospark drilled at the centre of the gasket. We used a high-pressure gas loader to compress gasses to high densities. The m-DACs were first loosely closed and mounted into a gearbox. The DAC and gearbox were then placed into a high-pressure gas loader (Top Industries). The system was first flushed with gasses to purge the circuit of impurities and then the sample chamber was pressurized. A 100-μm Lu foil was compressed between two diamonds to make it thinner than 100 μm and then loaded into a DAC with the H_2/N_2 gas mixture (99:1) and pressed to 2 GPa. We have not used any other gas ratios in our synthesis. All of the prepared samples were kept in a glovebox, closed and reopened to load with gas in a pre-purged hydrogen-rich environment. The glovebox environment was operated at levels at which O_2 and H_2O were each less than 0.5 ppm. The sample was heated in an oven overnight at 65 °C. After 24 h, the DAC was released to recover the sample. The samples were characterized using Raman and XRD studies. We have also used commercially available LuH_2/LuH_3. Owing to extremely complex synthesis techniques, controlling the correct stoichiometry with the right amount of hydrogen and nitrogen percentages was extremely challenging. The success rate of measuring a sample with superconducting properties was about 35%.

Raman spectroscopy, pressure and temperature determination

Raman spectroscopy was carried out using a custom micro-Raman setup in back-scattering geometry, along with Bragg notch filters, using a 532-nm Millennia eV laser, a Princeton Instruments HRS-500 spectrometer and a Pylon camera. Pressure determination was predominantly carried out using ruby fluorescence with the pressure gauge of Shen et al.[60] and the temperature correction of Datchi et al.[61]. Furthermore, pressure was also measured from the observed Raman peak location following several calibrations runs to determine the pressure dependence of the Raman modes. Pressure was measured during both cooling and heating. DT-670 silicon diodes were used to measure the temperature to five digits with our temperature controller (that is, two decimal places above 100 K or three decimal places below 100 K). The temperature uncertainty is larger than that precision as the diodes cannot be placed directly on the sample in a DAC and are placed outside the sample chamber and on the mechanical assembly around the DAC. Thus, the temperature uncertainty is dominated by thermal gradients between the temperature probes and the sample in the DAC, which are large while cooling down but much smaller while warming owing to the associated cooling and warming rates.

Electrical-resistance measurements

The resistance measurements were performed using standard DAC techniques with a standard four-probe technique similar to Dias et al.[62] that was used to measure the resistance of the sample. Either Al_2O_3 or diamond powder was packed into an insulating shell in which sample is loaded. Platinum foil (5 μm in thickness) cut electrodes are placed in contact with the sample, leading out of the pressure cell, allowing for transport measurements of the samples under pressure. Electrical resistance is thus measured in a four-probe configuration. The resistance measured on both warming and cooling at about 10 kbar is shown in Extended Data Fig. 13. A Keithley 6221 current source is used to apply a low-frequency (13 or 17 Hz) current across two of the probes and a SR860 lock-in amplifier with a 500× preamplifier measures the resulting voltage across the remaining two probes. For relatively high (on the order of about kΩ or more) resistance samples, a d.c. configuration is used, whereby a d.c. current is applied across two of the probes using a SRS CS580 current source, whereas the resulting voltage on the remaining two probes is measured with a DMM6500. In some cases, small residual resistance from the instrument offsets was subtracted from the measured voltage. We used a custom-built BeCu DAC for magnetic-field-dependent electrical-resistance studies using a custom-designed magnet from ColdEdge Inc. The *V*–*I* curves were obtained by supplying an a.c. current between 0 and 4 mA across the sample and measuring the voltage response, at temperatures above and below the critical temperature T_c. Above T_c, a current sweep from 0 to 4 mA was performed in 50 equally spaced steps and a linear response in the *V*–*I* curve is observed.

a.c. calorimetry measurements

For measurement of the specific heat capacity, a modified version of the conductivity setup is used[43]. Two sets of two probes are shorted in contact with the sample. The first, Ti, nichrome or Pt, serves as the heater. The second uses a pair of materials with differing Seebeck coefficients, either Pt/Ag or the standard alumel/chromel thermocouple pair. Typically, a NaCl insulating insert was used to isolate the sample better thermally. Extended Data Fig. 2, top shows the schematic representation of the setup and Extended Data Fig. 2, bottom shows the actual setup in the DAC.

To make measurements, the heater is driven at frequency f (typically between 50 and 500 Hz). The sample is thus ohmically heated and modulated at frequency $2 \times f$. Then the DAC is externally cooled or heated and the voltage measured across the thermocouple, using a lock-in amplifier reading at frequency $2 \times f$, which was shown to inversely proportional to the specific heat of the sample at any given temperature[63]. To verify appropriate behaviour, both current and frequency sweeps of the drive are performed, as shown in Extended Data Fig. 3. Frequency dependence is shown to exhibit a characteristic dome shape with a wide plateau, and the current sweep shows a quadratic dependence, as expected from ohmic heating. For this type of a.c. calorimetric measurements, the governing equation is given by[63]: $C_{a.c} = \frac{P}{\omega T_{a.c.}} F(\omega)$, with $C_{a.c.}$ being the a.c. heat capacity, P the driving power, ω the driving frequency, $T_{a.c.}$ the modulation in temperature of the sample and $F(\omega)$ the frequency response curve. The details of the frequency response curve are described elsewhere[63,64] but it depends on the relation between the three timescales of the system: $\tau_1 = 1/\omega_1$ is the timescale over which the sample thermalizes with the environment, that is, how fast heat dissipates from the sample to the NaCl in which the sample is sitting; $\tau_2 = 1/\omega_2$ is the timescale over which the heater, sample and thermocouple thermalize with each other; and $\tau_3 = 1/\omega_3$ is the timescale of the driving heater. The first two timescales, ω_1 and ω_2, are determined by the exact details of the experimental setup and will vary between runs, although care is taken so that $\omega_1 < \omega_2$ and the sample is able to thermalize with the heater and thermocouple before heat dissipates into the environment. This is accomplished by using the thermally insulating NaCl medium.

The third timescale is chosen by the frequency of the driving current and is an experimental parameter. Before performing an experiment, care is taken so that an appropriate driving frequency, or ω_3, is chosen. This is best seen by performing a frequency sweep of the drive, as shown in Extended Data Fig. 3, and shows the frequency response curve, $F(\omega)$. The response falls into three regions: an initial rise, a flat plateau and a final decline. The first region corresponds to $\omega_3 \ll \omega_1$; low-frequency drive results in heat dissipating to the environment, reducing the change in temperature of the sample. The third region corresponds to $\omega_3 \gg \omega_2$; the sample is not able to thermalize with the heater/thermocouple because the drive is too fast. The intermediate plateau between these two regions is where the response function is relatively constant with frequency, and there is good coupling between the heater, sample and thermocouple, with minimized loss to the environment. The final consideration is experimental. By using higher frequencies, the signal-to-noise ratio is improved and so a frequency between regions two and three is typically chosen.

Because the heater is driven at frequency f, the sample will experience temperature oscillations at frequency $2 \times f$ and the thermocouple will produce a voltage at $2 \times f$. The heat capacity is then inversely proportional to the measured voltage. As extra verification, a current sweep is performed to make sure the expected quadratic behaviour is produced, as shown in Extended Data Fig. 3, inset. A current is chosen at which acceptable signal is measured, but high currents are avoided to minimize d.c. heating that may occur on the sample. An example measurement and frequency sweep are shown in Extended Data Fig. 4.

a.c. magnetic-susceptibility measurements

All experiments were performed using a side-by-side double-coil technique as described by Debessai et al.[65]. In a single-coil setup, the measured voltage will be proportional to the average magnetic susceptibility of the volume contained in the coil. Owing to the geometry of the diamonds used within a DAC, the sample is necessarily a small fraction of the volume contained in the coil. We therefore use a double-coil setup whereby a second coil is connected in series but reversed relative to the first coil. We call the coil surrounding the sample the 'primary' coil and the second coil the 'dummy' coil. When connected in reverse, the signal from both coils essentially subtracts. Because the coils are near identical, when subtracted, the remaining difference should be because of the sample. In practice, the coils are never perfectly identical. The coils are hand wound in house to be as identical as possible, before being balanced for use in an experiment. To balance a pair of coils, first the pickup from the primary coil is measured and then the second coil is connected in reverse. While monitoring the pickup, one of the coils is slowly unwound until the measured pickup is as small as possible. The balancing is done until the signal is less than 1% of the single-coil reference value and most coils are balanced to 0.1–0.5%. This residual signal is what is measured as the (relatively) large background as compared with the signal strength coming from the sample. For improved resolution of the small signal voltages, a 500× preamplifier (SR554 Transformer Preamplifier) is often used. After dividing out the 500× preamplifier, the signal strengths are in the range of approximately 10–200 nV, depending on the sample and conditions. Owing to the small sample size, a large temperature-dependent background signal is observed, but the transition is clearly visible despite the large magnitude of the background. A background must be subtracted from the real part, yielding the final susceptibility signal. In this work, cubic or quadratic polynomial backgrounds were used (Extended Data Fig. 5), taking the measured voltage either immediately before or immediately after the transition.

d.c. magnetic susceptibility

We used the non-membrane-driven clamp-style pressure cell manufactured by HMD, a leading Japanese supplier of pressure cells for magnetometry. A schematic and actual picture of the HMD-13 cell can be found in the cell manual. This simplified design requires neither copper sealing rings nor a hydraulic press to achieve the pressure. The HMD-13 cell is designed with a BeCu construction and affords a minimized, uniform magnetic background, typically 4×10^{-7} e.m.u. gauss^{-1}. This pressure cell is a clamp cell, in which the sample is loaded with Daphne 7373 pressure medium inside a Teflon tube and closed using a Teflon capsule. Measurements were performed by directly measuring the HMD cell, which does not require a diamond or gasket. The samples that we use for this measurement are much larger compared with the DAC measurements. We have loaded large (approximately 150 μm × 100 μm) pieces into the Teflon capsule. The sample centre is known from the dimensions and pressure-cell compression, which is very standard in these experiments. The magnetization measurement was performed using a VSM option. The VSM option includes a linear motor transport for vibrating the sample, a coil set and the software application. An empty cell without the sample while keeping everything else the same was also performed to identify the cell background. The empty cell background is mostly constant with temperature. A linear or cubic background response was subtracted from the data, and we have applied a ten-point adjacent-average smoothing for all of the data (see Extended Data Fig. 14). The HMD-13 high-pressure cell is rated to reach a maximum pressure of up to 13 kbar. To achieve the highest pressure rated for this cell, the Teflon sample tube should be filled with as much sample as possible, with the minimum amount of pressure-transmitting medium required to fill the Teflon sample chamber. If the filling factor of the sample is small (limited by the synthesis procedure), achieving the rated pressure of 10 kbar will require substantially greater pressure-cell compression.

XRD and elemental analysis

For ambient X-ray powder diffraction measurements, microgram polycrystalline samples with typical sizes ($0.07 \times 0.05 \times 0.02$ mm^3) were placed onto a nylon loop and mounted in a Rigaku XtaLAB Synergy-S Dualflex diffractometer equipped with a HyPix-6000HE Hybrid X-ray Photon Counting area detector. The full data collection was carried out using a PhotonJet (Cu Kα) X-ray source with a detector distance of 34.0 mm. Data collection was performed using Gandolfi scans, which randomize the sample orientation in the beam by driving both phi and omega circles simultaneously. The scans were repeated for different kappa settings. CrysAlis Pro software was used to process and evaluate powder measurements. The Rietveld refinements of the ambient XRD data were performed using FullProf. High-pressure XRD measurements were performed using the Rigaku high-pressure kit designed for the Rigaku XtaLAB Synergy-S Dualflex diffractometer. Pressure was generated in custom-made PEAS-Q36 DACs. Two-hundred-micrometre conical diamonds were mounted on tungsten carbide bases with 70° opening angle. Data collection was carried out using a PhotonJet (Mo Kα) X-ray source with a detector distance of 80 mm. Samples were placed into either a rhenium or a tungsten gasket with a glycerine or methanol/ethanol pressure medium. Ag pieces (roughly 20 × 20 μm) were placed with the samples as a pressure marker. Pressure was estimated using the equation of state of Ag at 295 K. The pressure dependence of the lattice parameters was obtained from Le Bail refinement for the high-pressure XRD data using FullProf.

Elemental analysis was carried out using a PerkinElmer 2400 Series II CHNS/O Elemental Analyzer instrument for rapid determination of the carbon, hydrogen and nitrogen content in our samples. The instrument uses a helium carrier gas with an accuracy of about 0.3% for each element. The samples are crimp-sealed in special tin capsules before being loaded and burned in the instrument. Several different samples were prepared in an Ar glovebox to compare the elemental analysis results with samples that were prepared in air. Similar N content was detected in the samples tested in Ar atmosphere and air.

Simulations

Plane-wave DFT simulations using the Perdew–Burke–Ernzerhof[66] generalized gradient approximation functional were performed with Quantum ESPRESSO[67,68]. The convergence threshold for self-consistent field energies was 10^{-13} Ry, the convergence for forces was 10^{-6} Ry Bohr^{-1} and the stress convergence was 10^{-3} kbar. Gaussian smearing was used with a smearing width of 0.015 Ry. The phonons of cubic unit cells were calculated on $4 \times 4 \times 4$ $\vec{q}$-grids and those of rhombohedral primitive cells were calculated on $6 \times 6 \times 6$ $\vec{q}$-grids. Rhombohedral primitive cells were used whenever possible. The $\vec{k}$-grid density for the structural optimizations and phonon simulations was double that of the $\vec{q}$-grid in each direction, and the denser $\vec{k}$-grid for electron–phonon couplings was four times as dense as the $\vec{q}$-grid in each direction. In all visualizations and electron–phonon calculations, the 'simple' acoustic sum rule correction implemented in Quantum ESPRESSO was applied to the computed phonons. The PseudoDojo norm-conserving pseudopotentials were used with a kinetic energy cutoff of 100 Ry and charge density cutoff of 400 Ry (ref. [69]). Norm-conserving pseudopotentials were used to perform the electron–phonon calculations, along with a simplified Hubbard correction (DFT+U) applied to the *f* electrons[70,71]. A Hubbard U of 5.5 eV was selected in a similar fashion to the pseudopotential formulation of Topsakal and Wentzcovitch[72], that is, comparing the optimized lattice constants of the metal mononitride to experiment on a 0.5-eV interval. Those pseudopotentials were not used because they are at present incompatible with Quantum ESPRESSO density functional perturbation theory phonon calculations with a +U correction. The importance of describing the *f* electrons with DFT+U was tested by performing structural optimizations with the *f* electrons in core (using the pslibrary[73] PAW[74] pseudopotential for the metal) and with no Hubbard correction applied. In both of those cases, we found the lattice constants of all evaluated compounds to be underestimated compared with the available literature and experimental results. Neither of those two approaches were found to eliminate the dynamic instabilities of the trihydride (Extended Data Fig. 8b), although the instability at Γ was reduced in magnitude with the *f* electrons placed in core. To explore the dynamic instability of the trihydride, the displacements of NdD_3 (ref. [55]) were tested, as well as adding noise to each H position in the cubic unit cell in line with the displacements along one of the unstable optical phonon modes at Γ. The resulting structure was lower in energy and determined to be of the *Pmnm* space group, a subgroup of the XRD-determined *Immm* phase III structure (Extended Data Fig. 11b). Substitution of a N into a tetrahedral site of the distorted cubic representation of the *Pmnm* structure strongly reduced the distortions away from cubic (that is, cell edges that differ by less than 0.001 Å rather than 0.640 Å). The lighter lanthanoid hydrides $LnH(D)_x$ are known to tetragonally distort above $x \geq 2.3$ (refs. [75,76]), so it is possible that the phase II to III transformation is driven by the harmonic dynamic instabilities of the cubic trihydride. As there is no other hydrogen present and the transformation into phase III is recoverable to phase I, it is not likely that the sample is undergoing disproportionation to form a variant of the predicted tetragonal LuH_4 lattice[41].

It should be noted that LuH_2 has a particularly low uncorrected acoustic phonon frequency of about $-110\ cm^{-1}$ at Γ, which is not improved by doubling the size of the $\vec{k}$-grid in each direction or increasing the wavefunction cutoff. We found that, instead of representing the primitive cell of LuH_2 with the more highly symmetric lattice vectors of a fcc system, using a triclinic representation with *x* along ***a*** and *z* along ***c**** (which uses a D_3 electronic point group as opposed to O_h) has a negligible effect on the optimized lattice but alleviates the very negative uncorrected frequency at Γ. However, this creates weak dynamic instabilities of the acoustic phonons just off of Γ (see Extended Data Fig. 8), implying that anharmonic contributions may play a role in stabilizing the lattice, similar to how they were found to stabilize $Im\bar{3}m$ H_3S below 175 GPa (ref. [77]). Changing between the triclinic or more symmetric representation of the primitive unit cell's lattice vectors does not alleviate the optical dynamic instabilities of LuH_3. In addition, the phonon band dispersions for LuH_2 and ZB LuH in the highly symmetric lattice vectors were evaluated as a function of pressure up to 50 kbar. However, no notable change to their phonon band structures was observed, including the instability at *X* for ZB LuH (Extended Data Fig. 16).

Data availability

The authors declare that the data supporting the findings of this study are available in the article and its supplementary information files and from the public link https://doi.org/10.5281/zenodo.7374510. Source data are provided with this paper.

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Author contributions N.D.-G., E.S., R.M. and H.P. contributed equally to this work as co-first authors. E.S., D.D., N.D.-G., R.M., H.P. and R.P.D. contributed to performing the electrical-conductivity measurements. N.D.-G., N.K.-S., S.M., S.E.D. and R.P.D. contributed to performing a.c. magnetic-susceptibility measurements and analysed the data. N.D.-G., R.M. and R.P.D. contributed to performing heat-capacity measurements and the analysis. E.S., N.D.-G., R.M., D.D., H.P. and S.E.D. contributed to performing elemental analysis, EDX studies and XRD measurements. H.P., R.M., S.E.D. and R.P.D. contributed to performing Raman studies and H.P. and R.P.D. analysed the data. S.E.D. and A.S. performed structure analysis. H.P., S.E.D. and R.P.D. performed the magnetization measurements using a PPMS and R.P.D. analysed the data. K.V.L. and A.S. performed the simulations and analysed the data and chemistry protocol. N.D.-G., K.V.L., A.S., S.E.D. and R.P.D. wrote the paper. All authors discussed the results and commented on the manuscript. R.P.D. conceived the project and oversaw the entire project.

Competing interests The University of Rochester (U of R) has patents pending related to the discoveries of R.P.D. in the field of superconductivity. R.P.D. is a cofounder and chairman of the board of Unearthly Materials Inc. (UM), a Delaware corporation. UM has licensing agreements with U of R related to the patents, proprietary interests and commercialization rights related to the scientific discoveries of R.P.D. UM, U of R and R.P.D. are subject to non-disclosure and confidentiality agreements. A.S. is a cofounder, president, chief executive officer and board member of UM.

Additional information
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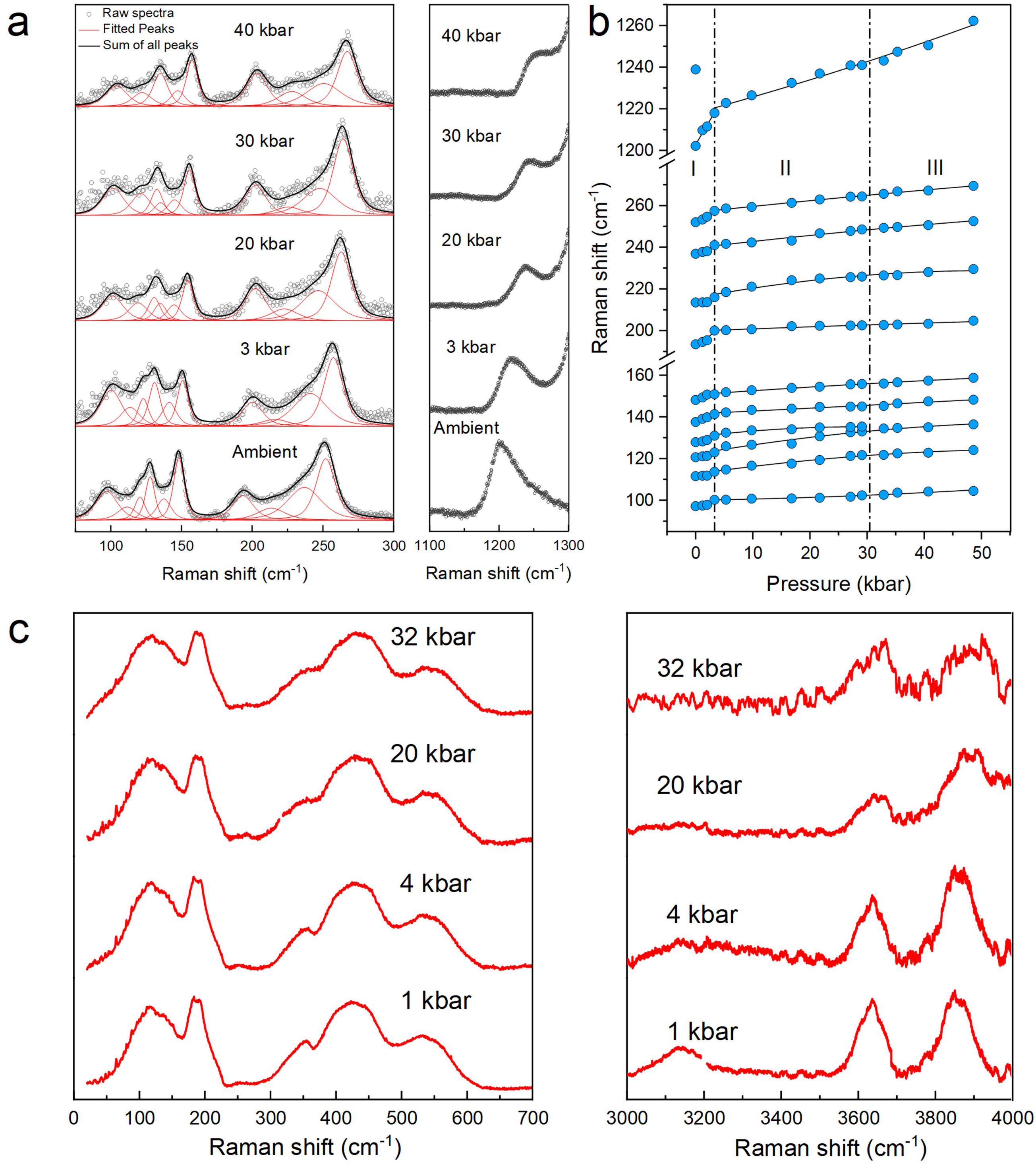
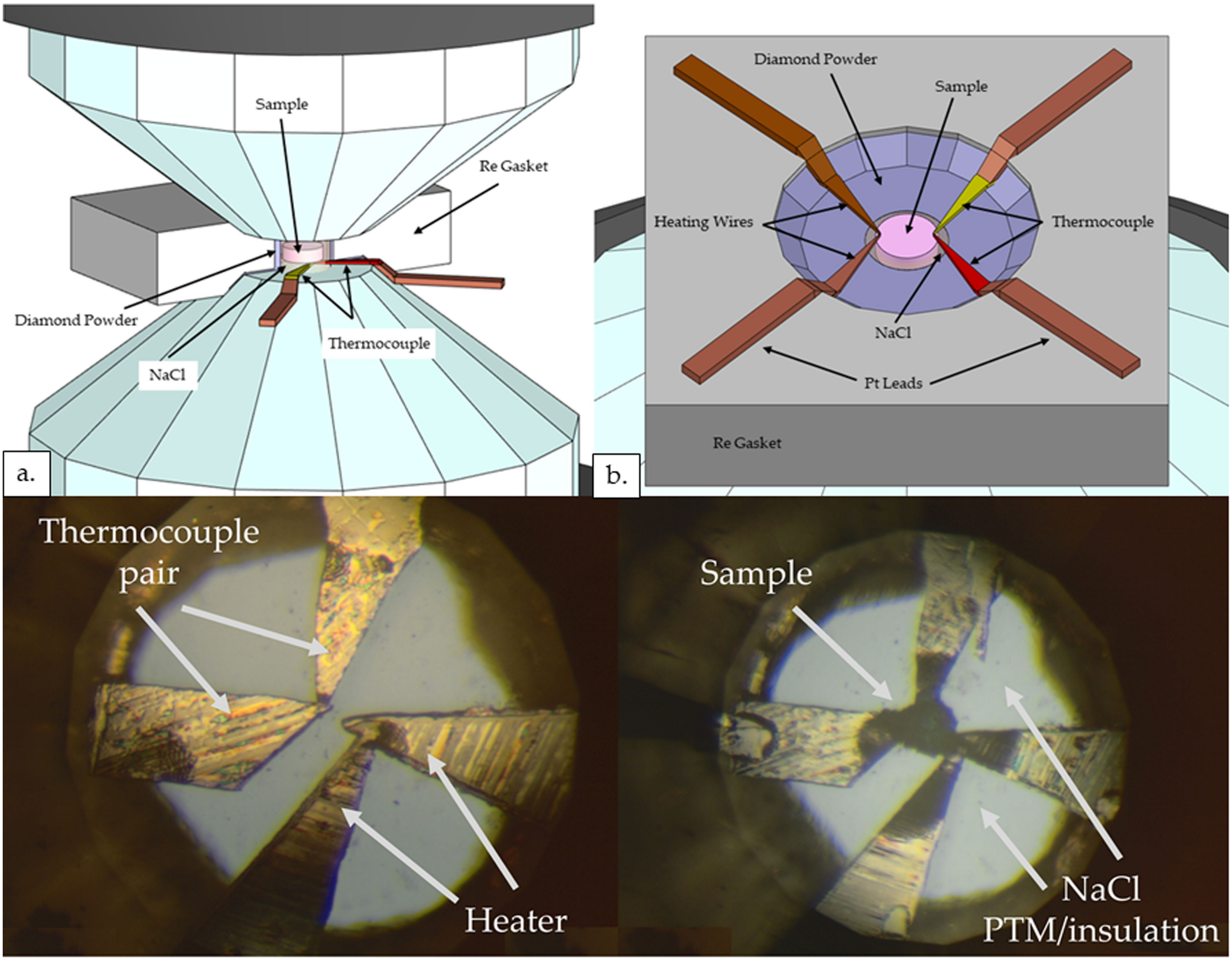
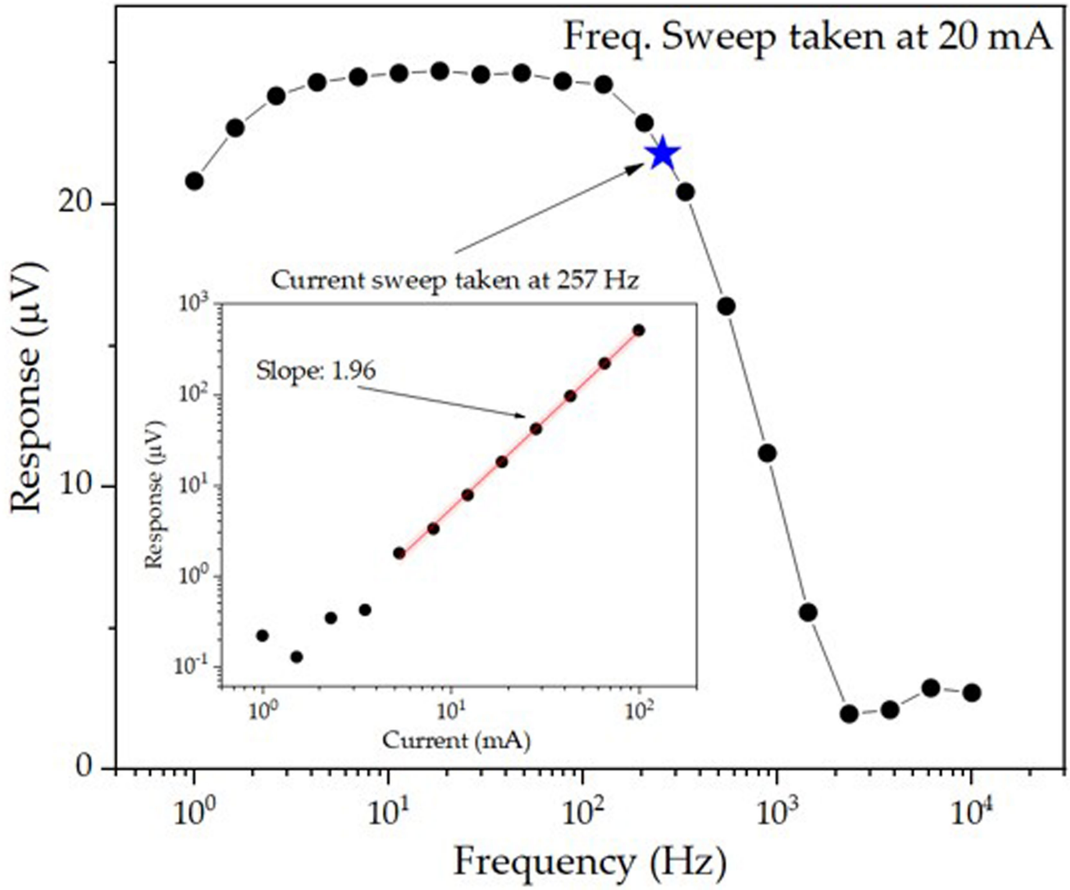


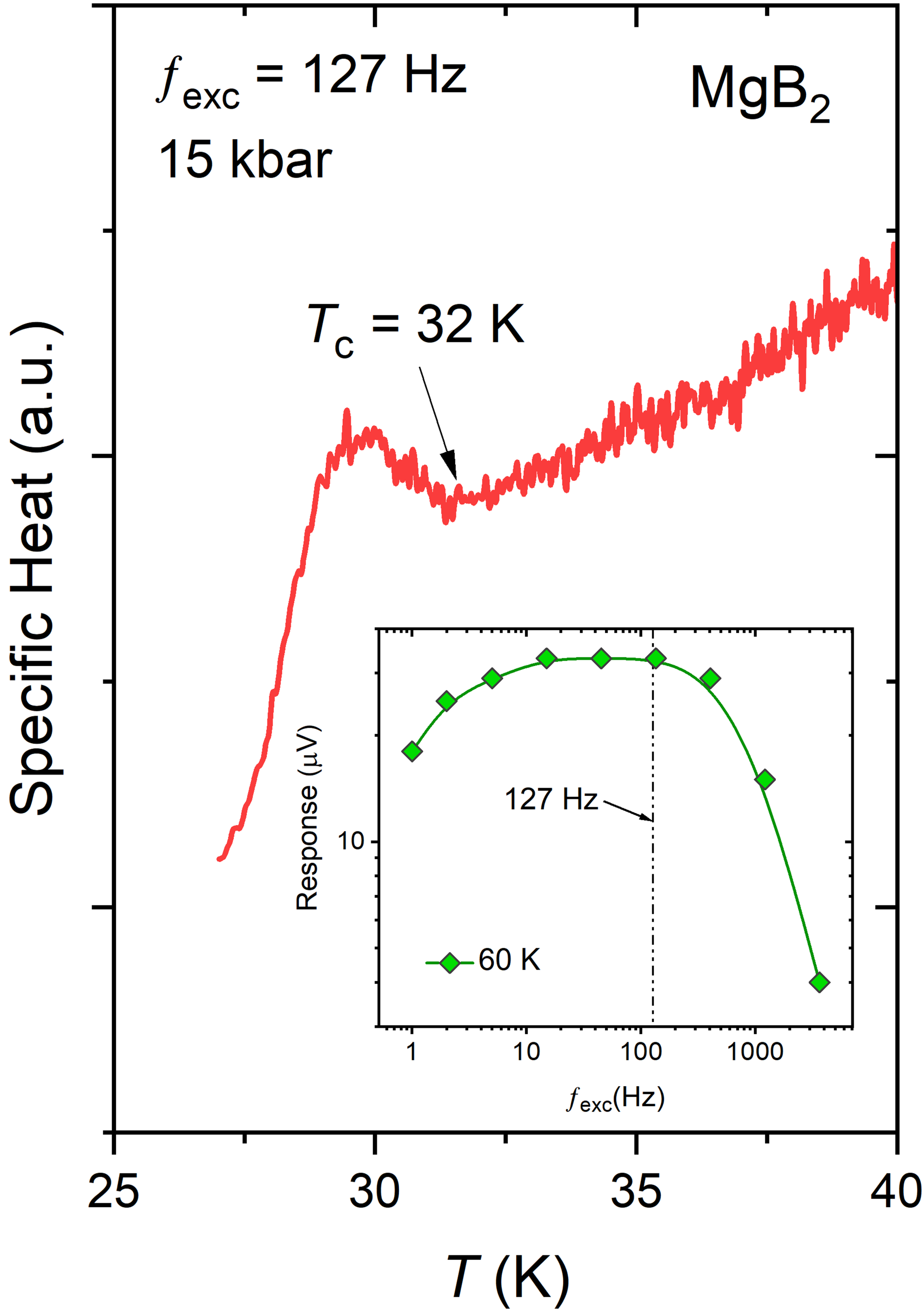
Extended Data Fig. 1 | Raman spectra. a, The spectral deconvolution of Raman spectra of compound A on compression. **b**, The Raman shift versus pressure of compound A at high pressures, indicating the three distinct phases. **c**, The spectral deconvolution of Raman spectra of compound B on compression.



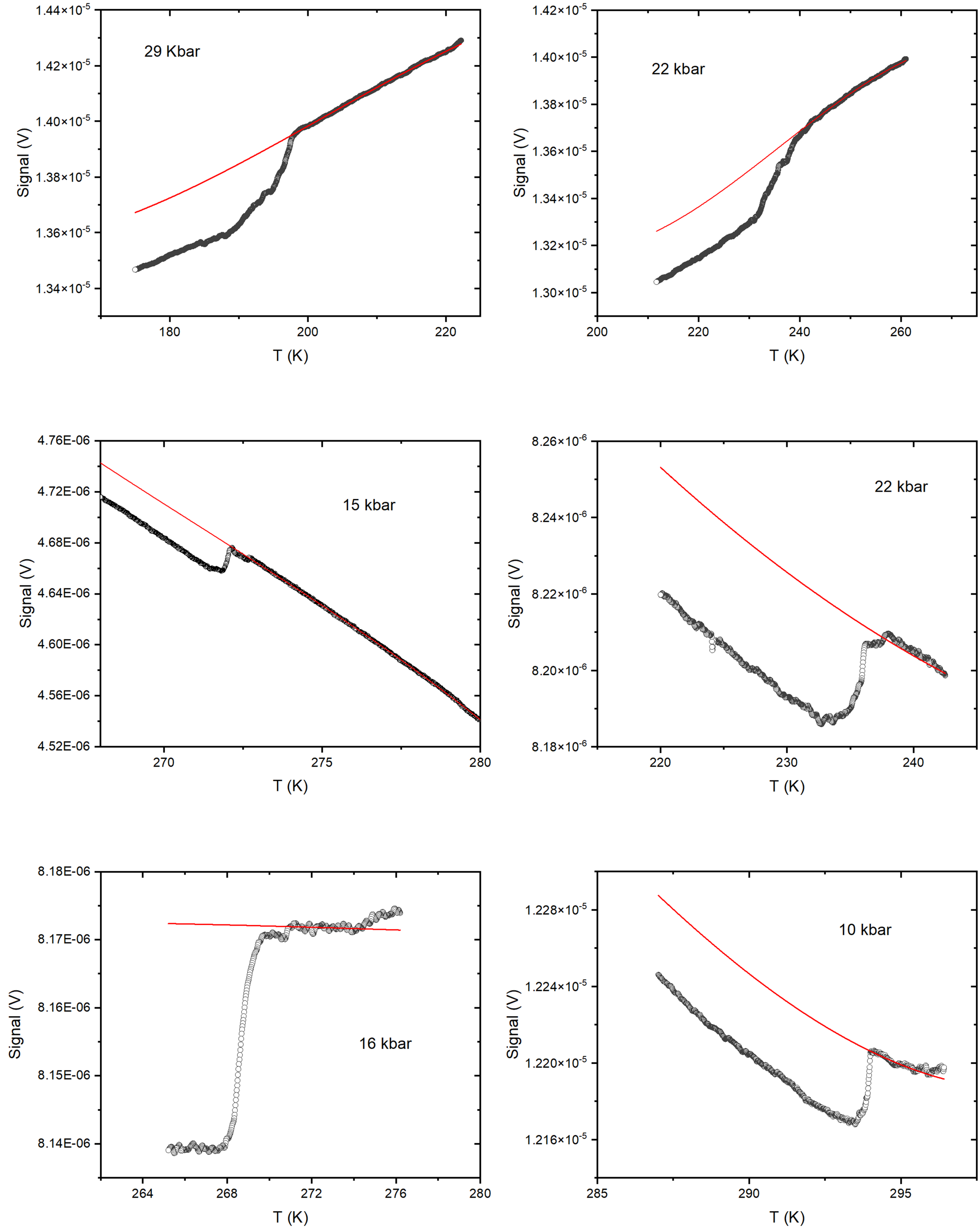
Extended Data Fig. 2 | The heat-capacity setup. Top, schematic rendering of the new a.c calorimetry technique (not to scale). The sample is surrounded by a NaCl insert with a heater and thermocouple making contact with the sample. **a**, View of the preparation as seen from the side showing the thermocouple making contact with the sample inside the DAC. **b**, View of the preparation as seen from the top of the sample area showing the configuration of heater, thermocouple and Pt leads. Bottom left, heat-capacity setup before loading sample. The thermocouple consists of a shorted alumel/chromel pair. The heater pair consists of a shorted metal, nichrome, Ti or Pt. When driven at frequency f, the sample temperature modulates at frequency $2 \times f$, which manifests as a voltage on the thermocouple pair that can be measured by a lock-in amplifier. Bottom right, after the sample is loaded, in contact with both the heater and the thermocouple, a small piece of NaCl is placed on top to thermally insulate it from the diamond.



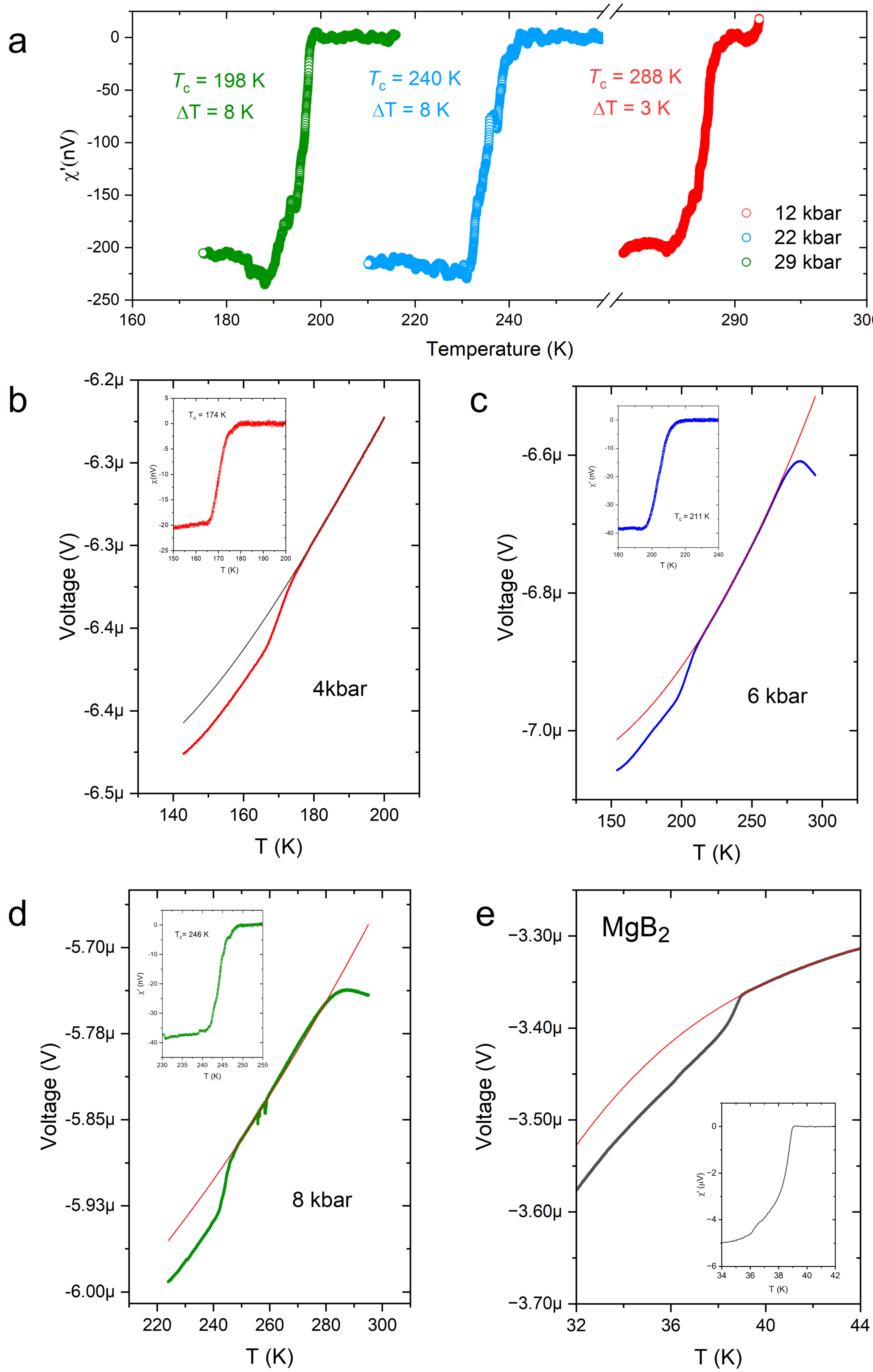
Extended Data Fig. 3 | Frequency response. Frequency and current sweeps measured on a heat-capacity setup before running the experiment. The frequency sweep shows the characteristic plateau and the current sweep demonstrates quadratic dependence, as expected from ohmic heating.



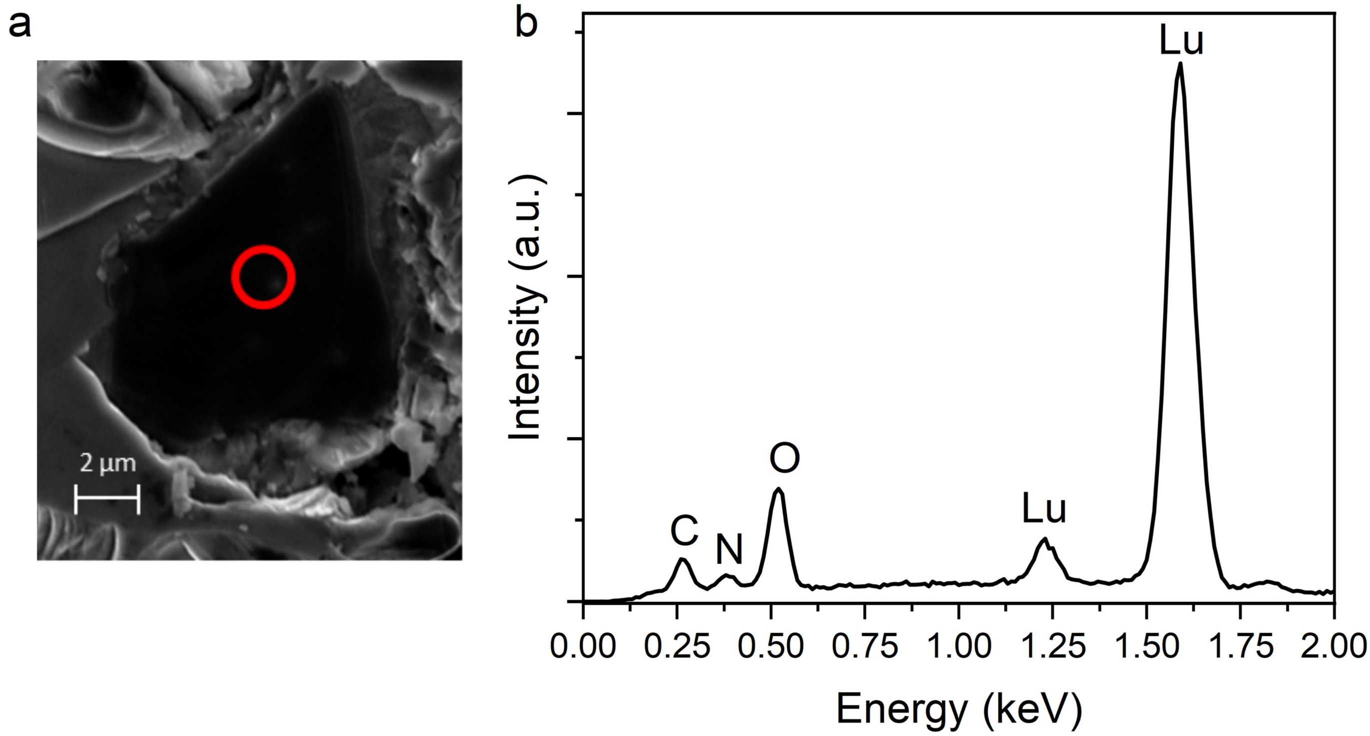
Extended Data Fig. 4 | Heat capacity. Specific heat capacity of MgB_2 as a function of temperature at 15 kbar and 127 Hz. The superconducting signature is clearly observed at 32 K. Inset, recorded lock-in voltages during the frequency sweeps at 60 K.



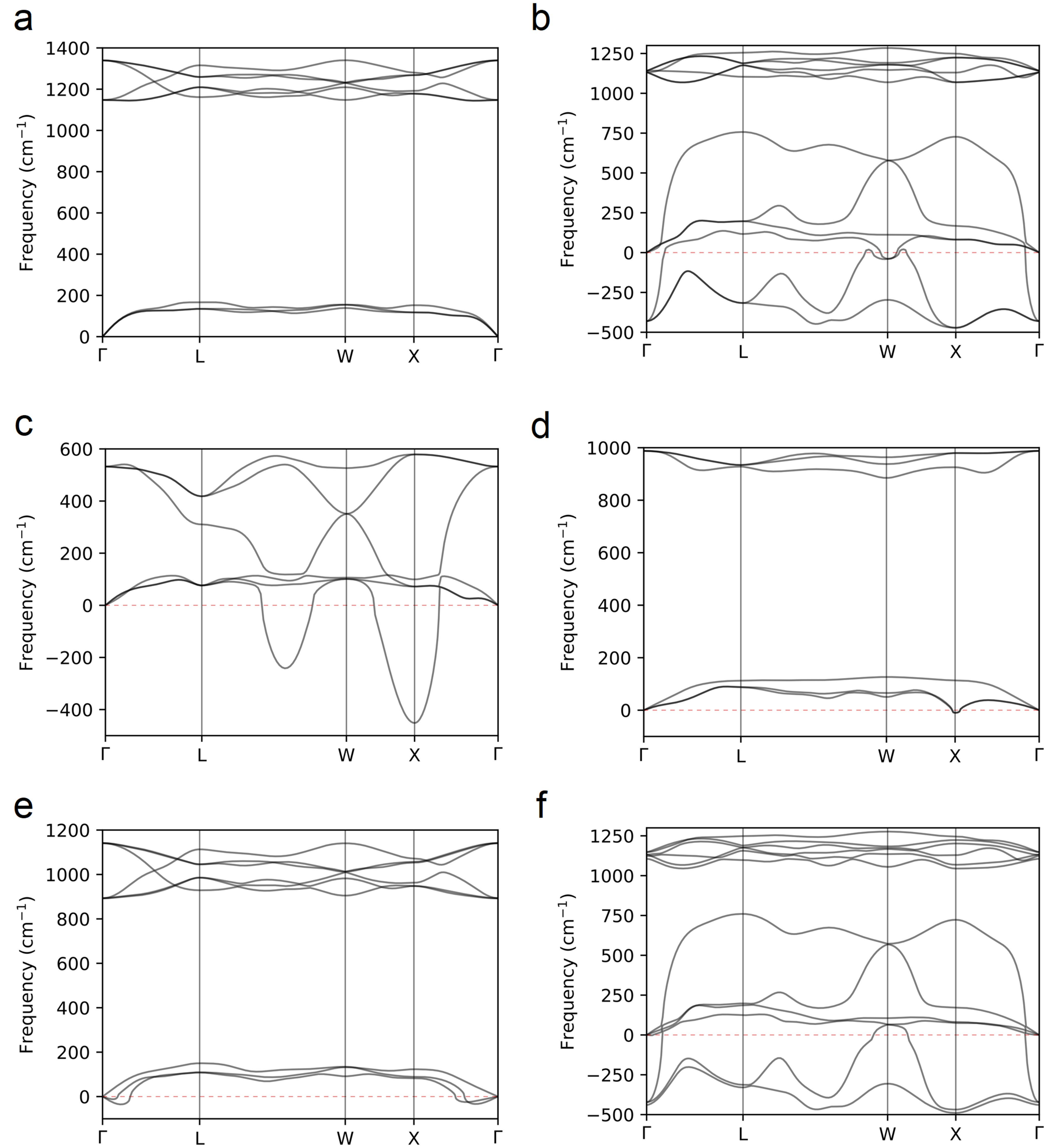
Extended Data Fig. 5 | a.c. susceptibility data before background subtraction. Voltage in volts versus temperature plots at different pressures before the background subtraction. Cubic or quadratic polynomial background was used for background subtraction for susceptibility data. This figure shows fittings with cubic or quadratic polynomials indicated by the red lines. For a.c. susceptibility data, the background subtraction was done mainly for visualization purposes.



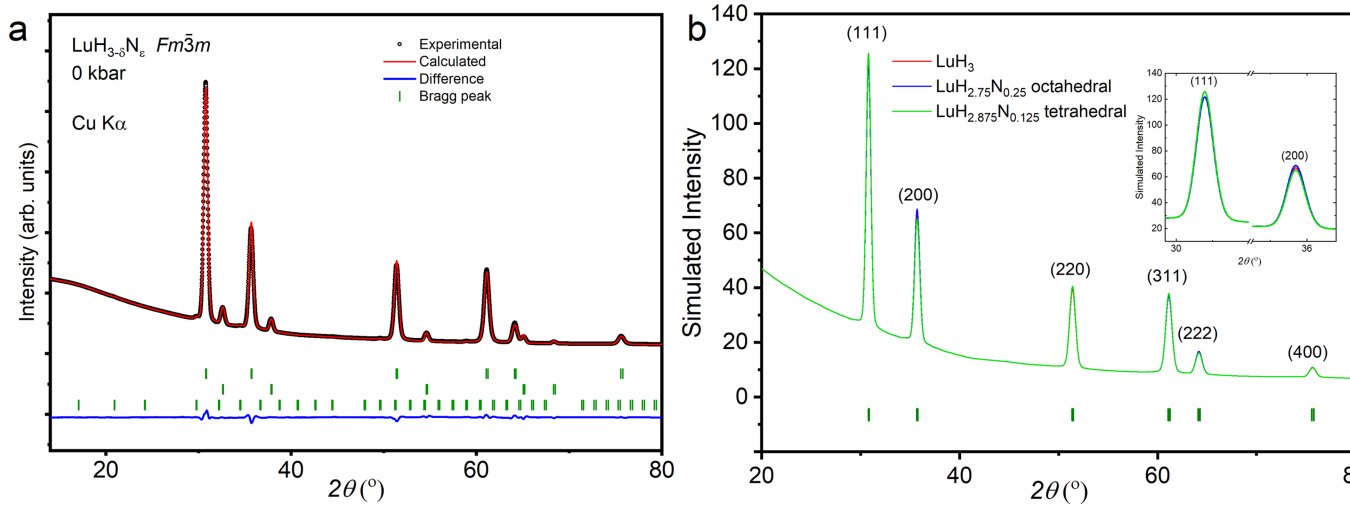
Extended Data Fig. 6 | Further a.c. susceptibility measurements. **a**, The a.c. susceptibility in nanovolts versus temperature for a larger sample of the N-doped Lu hydride system at select pressures from run 2, showing large diamagnetic signal of the superconducting transition owing to the large volume of the sample. The superconducting transition shifts rapidly under pressure to lower temperatures. a.c. susceptibility measurements taken over broader temperature ranges for N-doped Lu hydride at 4 kbar (**b**), 6 kbar (**c**) and 8 kbar (**d**). The red line in **b**–**d** is the quadratic fit for the background and the insets show the signals with the background subtracted. **e**, a.c. susceptibility measurements of MgB_2 as a function of temperature using exact same coil set up as the test sample.



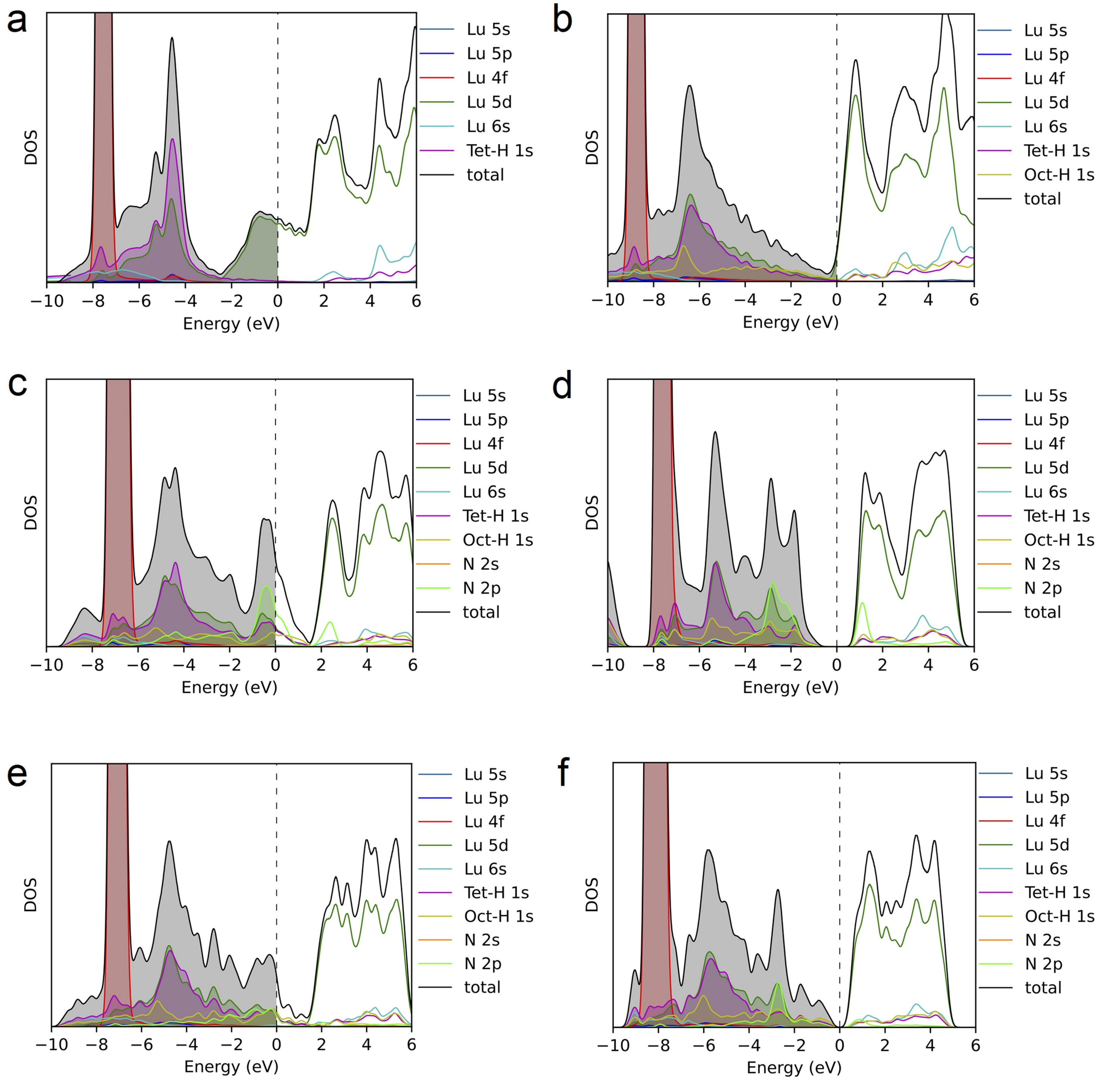
Extended Data Fig. 7 | EDX measurements. For EDX measurements, samples were prepared by mounting on an aluminium pin mount with double-sided carbon tape. The samples were then imaged using a Zeiss Auriga scanning electron microscope. Regions of interest were chosen by comparing the scanning electron microscopy image to a white-light image taken beforehand. EDX measurements were performed in the Zeiss Auriga scanning electron microscope with a driving energy of 15 kV and collected and analysed using an EDAX detector with the EDAX APEX software. Carbon and aluminium peaks seen in the EDX spectra originating from the carbon tape and aluminium mount required to place the samples into the scanning electron microscope vacuum chamber. EDX measurements provide further evidence for the presence of nitrogen in our samples.



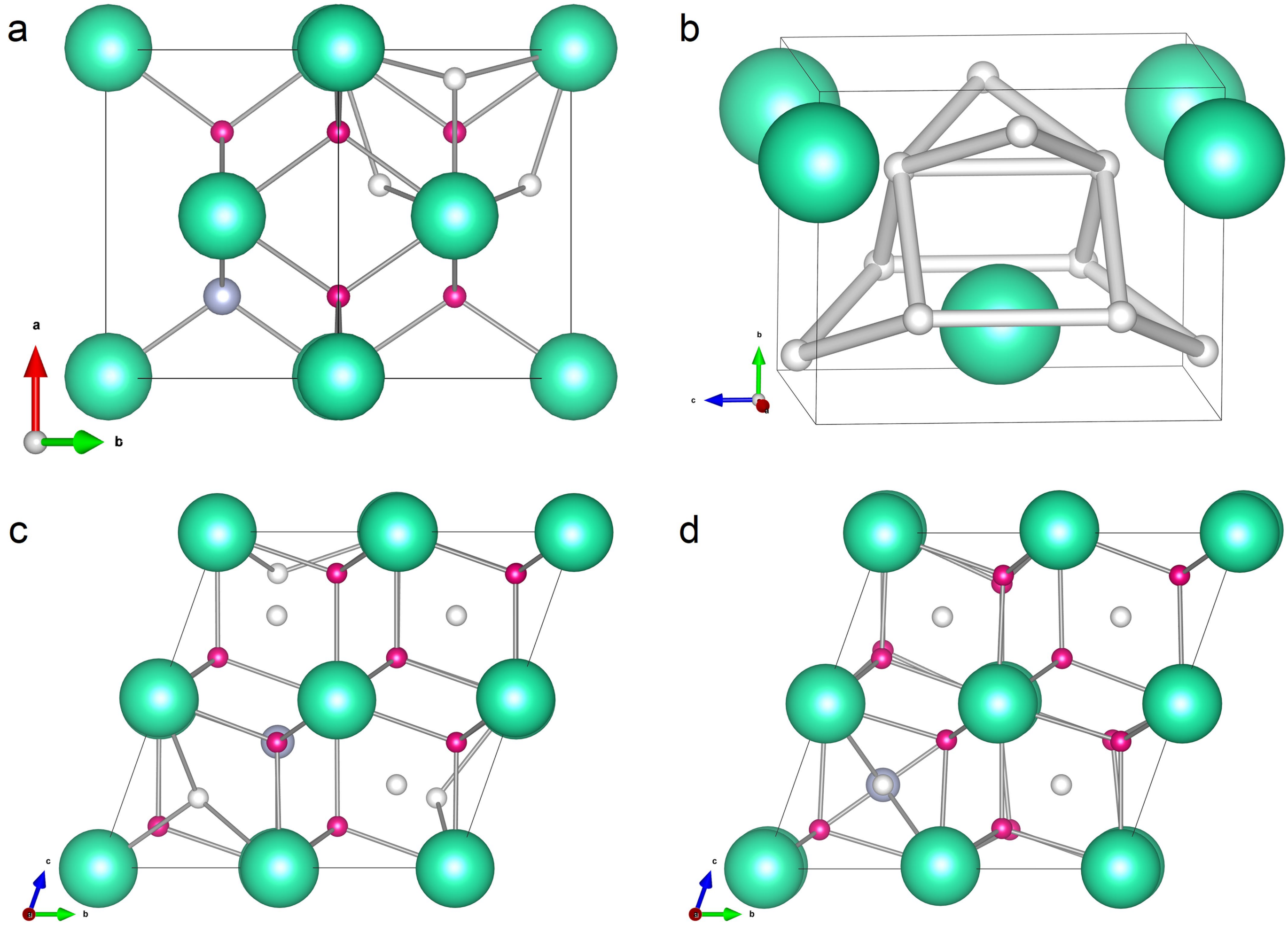
Extended Data Fig. 8 | Phonon bands of stoichiometric Lu hydrides. The calculated phonon band structures of 0 kbar LuH_2 in the fluorite structure (**a**), $Fm\bar{3}m$ LuH_3 (**b**), LuH in the RS structure (**c**) and LuH in the ZB structure (**d**). **e**, The calculated phonon band structures of 0 kbar LuH_2 in the fluorite structure using a triclinic representation of the lattice vectors with x parallel to a and z parallel to c^*, as opposed to the more highly symmetric lattice vectors for a primitive cell of a fcc cell; in this representation, the structure is represented with D_{3d} point-group symmetry as opposed to O_h point-group symmetry as in **a**. **f**, The calculated phonon band structures of 0 kbar LuH_3 using the same triclinic representation of the lattice vectors and point-group symmetry as in **e**.



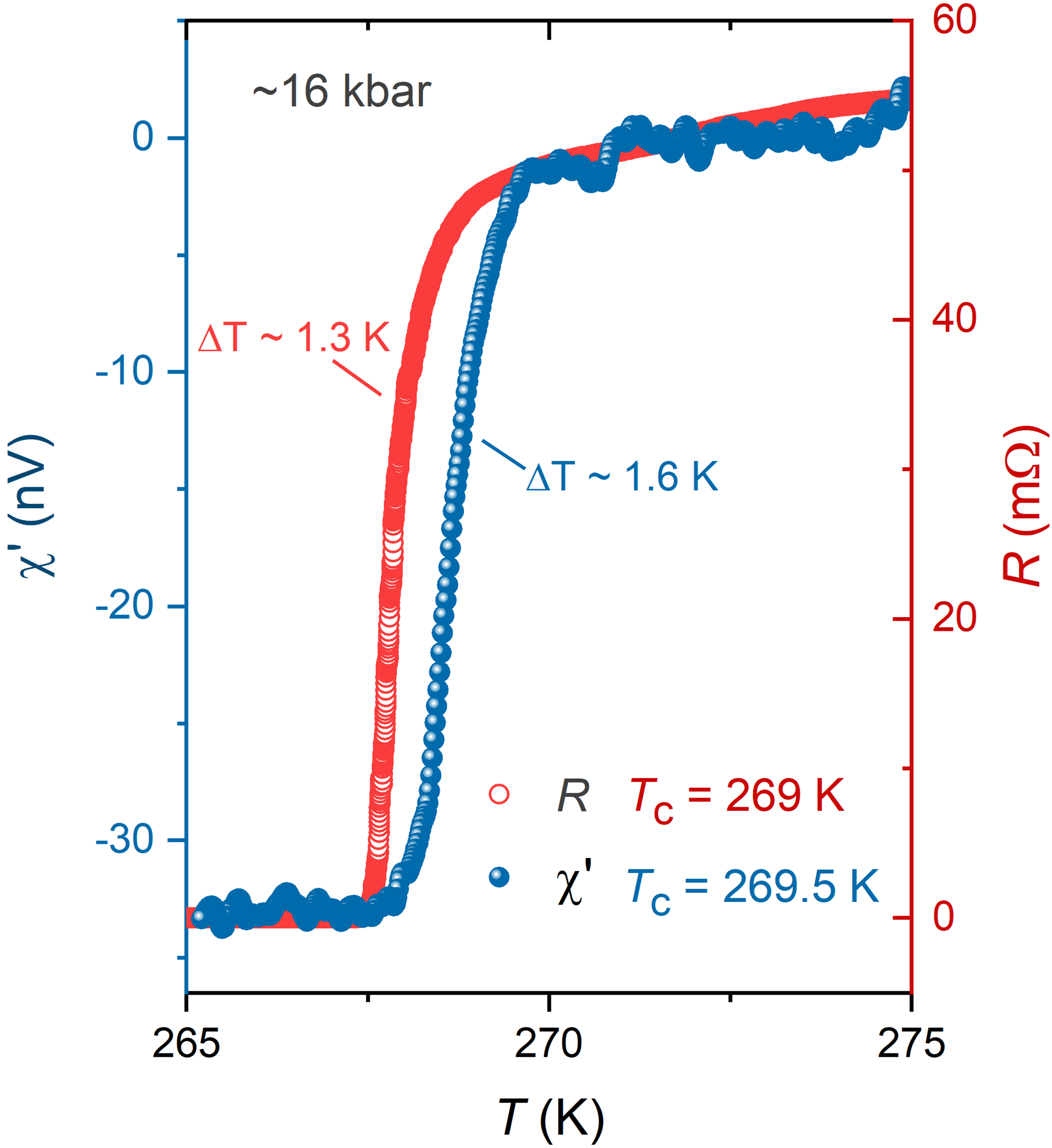
Extended Data Fig. 9 | Rietveld refinement of site occupancies. a, Rietveld refinement of the X-ray powder diffraction data collected at 295 K with Cu Kα radiation with refining the occupancy of the tetrahedral interstitial site with N for nitrogen-doped lutetium hydride. **b**, Simulation of the XRD pattern with Cu Kα wavelength for LuH_3 (red), LuH_3 with a N replacing a single H in an octahedral site (blue) and a tetrahedral site (green). Rietveld refinement of the X-ray powder diffraction data of ground powder sample was performed with an attempt to investigate the possible N substitution in nitrogen-doped lutetium hydride. We note here that XRD is mostly dominated by heavy Lu atoms.



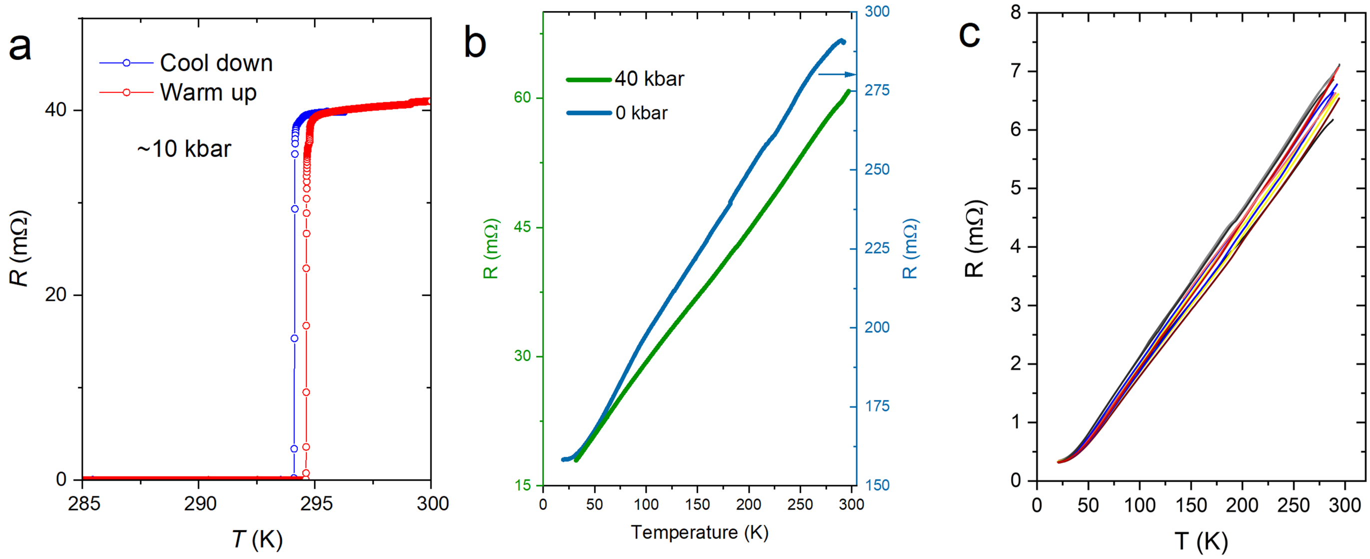
Extended Data Fig. 10 | Projected density of states. The atom and angular momentum projected partial density of states of LuH_2 in the fluorite structure (**a**); $Fm\bar{3}m$ LuH_3 (**b**); the cubic cell of $Fm\bar{3}m$ LuH_3 with a N substituted for a H in an octahedral (**c**) and tetrahedral (**d**) interstice; and a 2 × 2 × 2 supercell of the rhombohedral primitive cell of $Fm\bar{3}m$ LuH_3 with a N substituted for a H in an octahedral (**e**) and tetrahedral (**f**) interstice. In the legends, Oct- means hydrogens in the octahedral interstices and Tet- means hydrogens in the tetrahedral interstices. Each channel is summed over all similar atoms in the unit cell and the plots are scaled to represent a maximum value of 2.5 states eV^{-1} per formula unit.



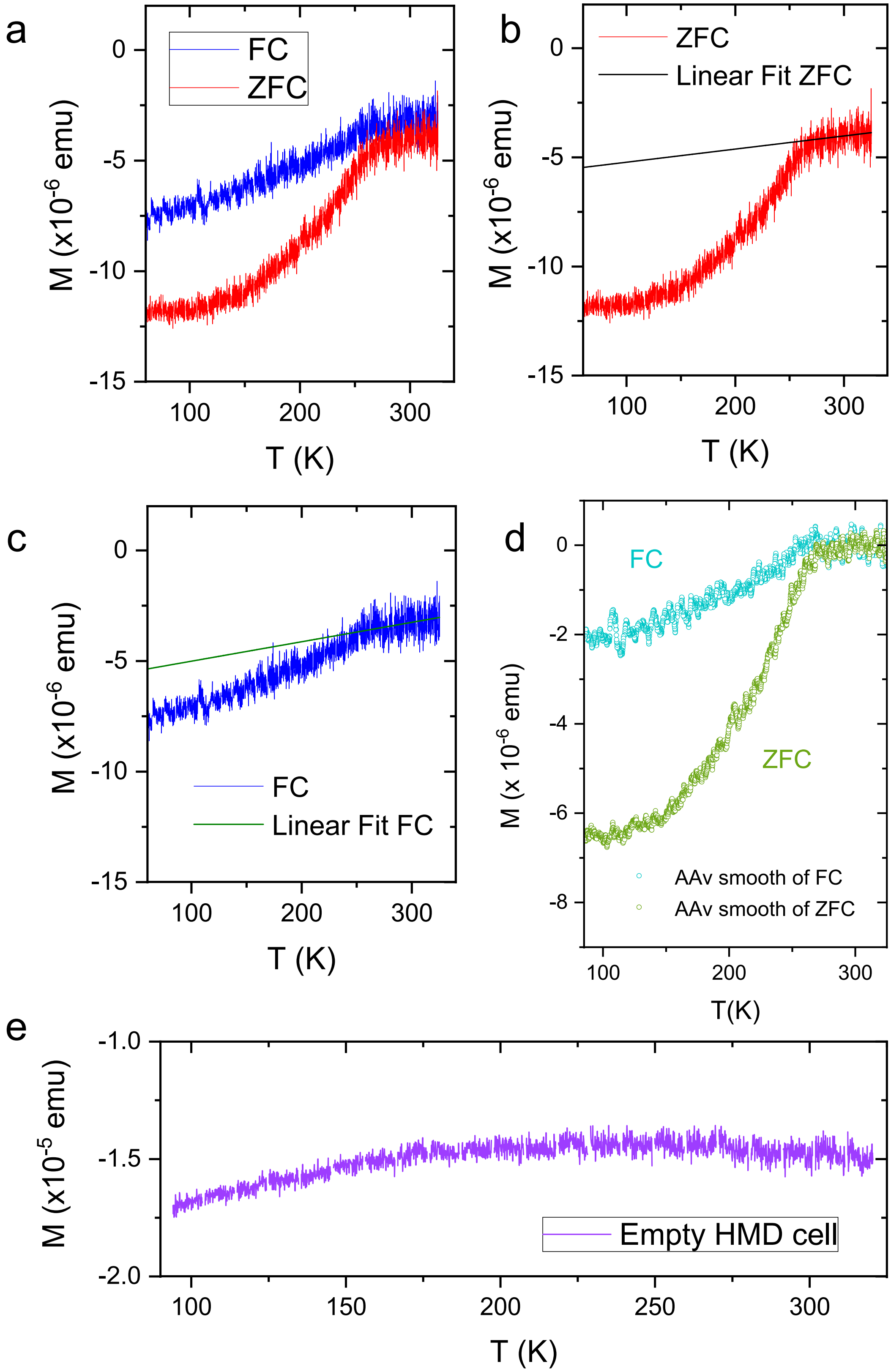
Extended Data Fig. 11 | Distorted structures predicted by DFT. a, The distortions to the octahedral hydrogens observed by substituting a N atom for a tetrahedral atom in a single unit cell of *Fm*$\bar{3}$*m* LuH_3. **b**, The *Pmnm* LuH_3 structure found by perturbing the cubic *Fm*$\bar{3}$*m* unit cell of LuH_3, which suggests possible light-atom positions in phase III. **c**, The lattice distortions from substituting a N into a tetrahedral interstice in a 2 × 2 × 2 supercell of the rhombohedral primitive of LuH_3. **d**, The lattice distortions from substituting a N into an octahedral interstice in a 2 × 2 × 2 supercell of the rhombohedral primitive of LuH_3. The lutetium atoms are green, the nitrogen atoms are lavender and the hydrogen atoms in octahedral interstitial sites are white and those in tetrahedral interstitial sites are pink. In **b**, there is no distinction made between the hydrogen atom sites, so they are all white.



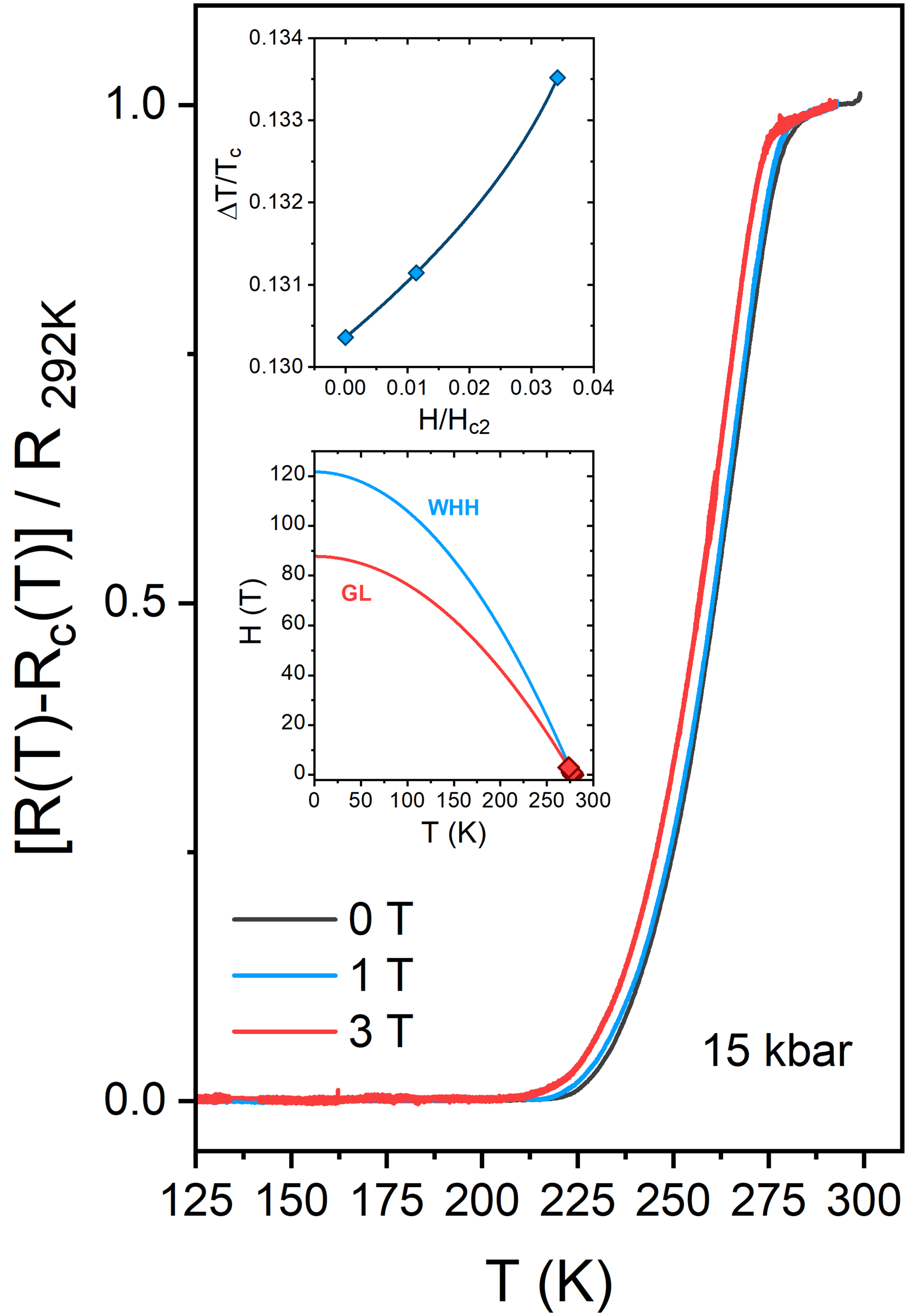
Extended Data Fig. 12 | Superconducting transition widths. For comparison, the superconducting transition obtained from electrical measurements and a.c. susceptibility measurement at a similar pressure (16 kbar) is shown by red and blue, respectively. The transition width of the resistance drop is 1.3 K and 1.6 K for the a.c. magnetic susceptibility measurement.



Extended Data Fig. 13 | Low-temperature electrical-resistance behaviour of N-doped Lu–H systems. a, The resistance measured on both warming and cooling at about 10 kbar. **b**, Temperature-dependent electrical resistance of phases I and III, showing the non-superconducting state. **c**, Four-probe electrical-resistance measurements of different Lu–H–N samples, which consistently shows highly metallic behaviour with decreasing temperature.

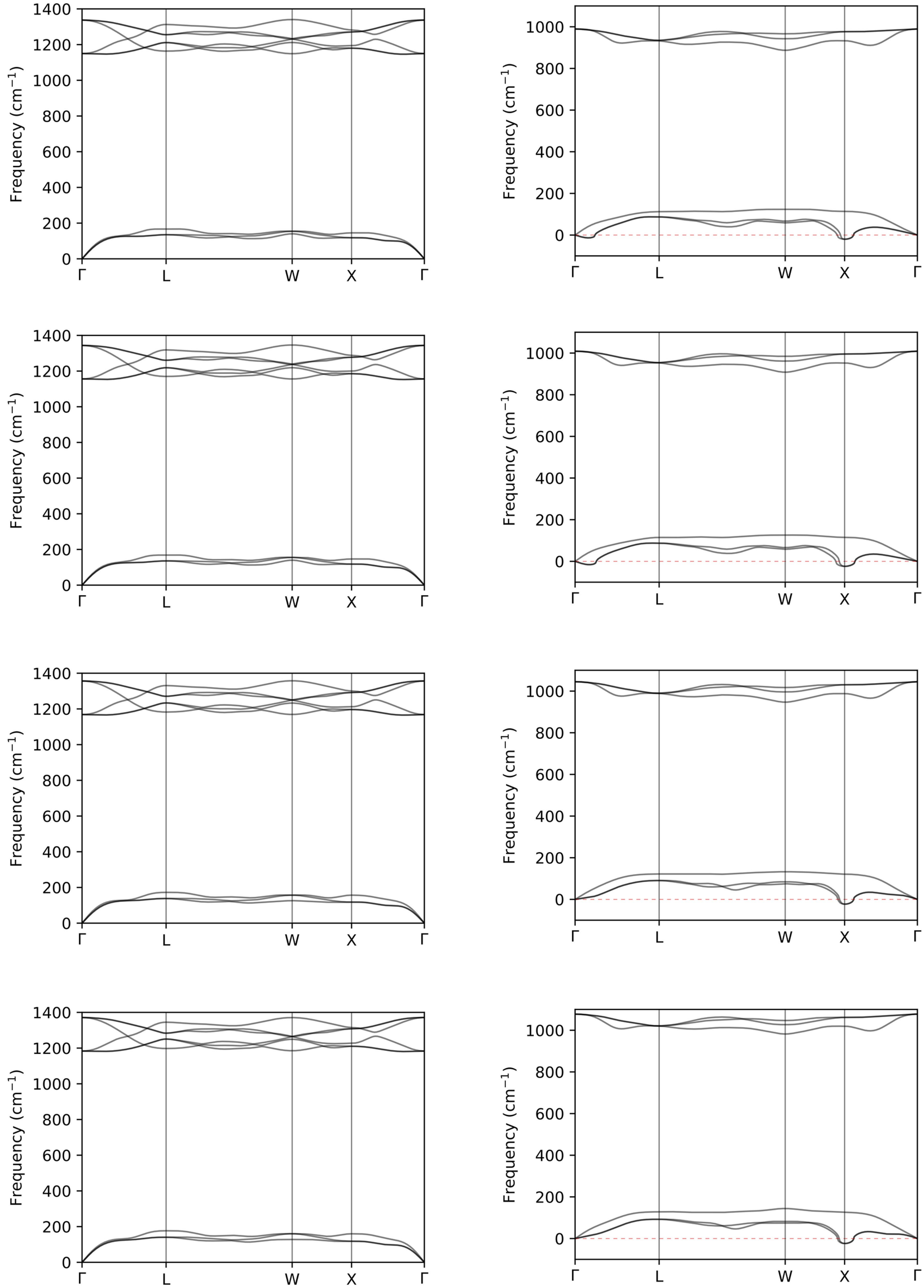


Extended Data Fig. 14 | Magnetic-susceptibility background and smoothing. a–c, The ZFC and FC magnetization versus temperature at 8 kbar used to construct Fig. 3a, along with a linear fit to the data at temperatures above the transition temperature, which was used for the background subtraction. **d**, The ZFC and FC curves with the linear backgrounds shown in **b** and **c** subtracted out, as well as with a ten-point adjacent-average smoothing applied. **e**, The measured cell background at 60 Oe for the HMD cell used for the d.c. measurements.



Extended Data Fig. 15 | See next page for caption.

Extended Data Fig. 15 | Electrical-resistance behaviour under magnetic field. Low-temperature electrical-resistance behaviour under magnetic fields of $H = 0$ T, 1 T and 3 T (increasing from right to left) at 15 kbar. In this study, the superconductivity of nitrogen-doped lutetium hydride is suppressed by the application of a 3-T external magnetic field, reducing T_c by about 5 K at 15 kbar, further confirming a superconducting transition. The temperature dependence of the resistance of a simple metal is written as: $R(T) = R_o + aT^2 + bT^5$. We fit the data below $T < 220$ K for each field, at which the resistance goes to the minimum value, to that function and subtracted it out. Inset top, the superconducting transition width, ΔT_c, at 15 kbar slightly increases under external magnetic fields. The ΔT_c has a good linear relationship with the applied magnetic field, as expected from the percolation model. The superconducting transition width is defined here as $\Delta T_c = T_{90\%} - T_{10\%}$, in which $T_{90\%}$ and $T_{10\%}$ are the temperatures corresponding to 90% and 10% of the resistance at 292 K, respectively. Fitting to the linear relation of $\Delta T_c = \Delta T_c(0) + kH_{c2}$, in which $\Delta T_c(0)$ is the width at zero external field and k is a constant, provides the values $\Delta T_c(0) = 36.3$ K and $k = 0.07$ KT^{-1}. The large transition width at zero field indicates sample inhomogeneities, which is typical for high-pressure experiments. Inset bottom, the temperature dependence of the upper critical field, $H_c(T) = H_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$, can be expressed using GL theory or the conventional Werthamer–Helfand–Hohenberg model. The GL model in the limit of zero temperature yields $H_{c2}(0) \approx 88$ T. From the Werthamer–Helfand–Hohenberg model in the dirty limit, $H_{c2}(0)$ can be extrapolated from the slope of the H–T curve as $H_{c2}(0) = 0.693 \left| \frac{dH_{c2}}{dT} \right|_{T=T_c} T_c$, which yields roughly 122 T.



Extended Data Fig. 16 | Phonon bands of pressurized stoichiometric Lu hydrides. The calculated phonon band structures of LuH_2 in the fluorite structure (left) and LuH in the ZB structure (right) at 0 kbar (top row), 10 kbar (second row), 30 kbar (third row) and 50 kbar (bottom row). The electronic smearing width is 0.005 Ry and the lattice vectors are the highly symmetric ones for a fcc cell. Negligible change in the computed electron–phonon couplings or logarithmic frequency is seen for LuH_2 on pressurization.

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Absence of near-ambient superconductivity in $LuH_{2\pm x}N_y$

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Summary

Recently near-ambient superconductivity was claimed in nitrogen-doped lutetium hydride[1]. This stimulates a worldwide interest about exploring room temperature superconductivity under low pressures. By using a high pressure and high temperature synthesis technique, we have successfully obtained the nitrogen doped lutetium hydride ($LuH_{2\pm x}N_y$) with a dark-blue color and a structure with the space group of $Fm\bar{3}m$ evidenced by x-ray diffraction. This structure is the same as that reported in ref. 1, with a slight difference in lattice constant. The Raman spectroscopy also shows similar patterns between our samples and that in ref. 1. The energy dispersive X-ray spectroscopy (EDS) confirmed the existence of

nitrogen in the samples. At ambient pressure, we witness a metallic behavior from 350 down to 2 K. By applying pressures from 2.1 to 41 GPa, we observe a gradual color change from dark-blue, to violet, to pink-red. By measuring the resistance at pressures from 0.4 to 40.1 GPa, we have seen a progressively improved metallic behavior without showing superconductivity down to 2 K. Temperature dependence of magnetization under high pressures shows a very weak positive signal between 100 and 320 K, and the magnetization increases with magnetic field at 100 K, all these are not expected for superconductivity at 100 K. Thus, we conclude the absence of near-ambient superconductivity in this nitrogen-doped lutetium hydride under pressures below 40.1 GPa.

Main text

Metallic hydrogen and hydrogen-rich materials provide interesting platforms for searching room temperature superconductivity since it was proposed theoretically by Ashcroft[2]. However, experimentally it is difficult to achieve high temperature superconductivity (HTS) under low pressures[3, 4]. Then theorists proposed that the polyhydrides may have the potential to realize HTS due to the effect of internal chemical pressure[5]. Later, HTS was observed by experiments in H_3S with a transition temperature (T_c) above 200 K under a high pressure (~200 GPa) as predicted by the theories[6-8]. After that, more and more hydrogen-rich superconductors have been discovered, such as LaH_{10}, CaH_6, *etc.*[9-15]. However, according to the basic understanding on the theory of Bardeen-Cooper-Schrieffer (BCS), HTS would rely on very strong electron-phonon coupling with a very high Debye temperature. According to the McMillan's formula, if we assume a Debye temperature of 500 K, the Coulomb screening constant $\mu^* = 0.13$, the requested electron-phonon coupling constant λ would be as large as 12.2 for T_c = 100 K. This huge λ cannot allow a stable lattice structure, thus this HTS can only be achieved in such systems when they are protected by extremely high pressures.

Recently, superconductivity at about 294 K in N-doped Lu hydride under only 1 GPa was reported[1], which is extremely interesting and important if the observation could be repeated. As reported by Dasenbrock-Gammon *et al.*[1], the dark-bluish ternary compound (with the formula $LuH_{3-\delta}N_{\varepsilon}$ used by them) can be tuned to a near-ambient superconductor by a relatively low pressure (1-2 GPa), accompanied with a color change from blue to pink and red. Actually, in previous experiments, superconductivity with much lower T_c was reported by other groups under high pressures in Lu hydrides[16,17]. Thus, comparing with above results of Lu hydrides, the discovery of near-ambient superconductivity in N-doped lutetium hydride is really striking. It generates great curiosity whether room temperature superconductivity really exists in this N-doped lutetium hydride under relatively low pressures.

Physical properties at ambient pressure

Figure 1**a** shows the X-ray diffraction (XRD) pattern and Rietveld refinement for the $LuH_{2\pm x}N_y$ sample. As we can see, the experimental data can be well fitted by the structure of LuH_2 with the space group of $Fm\bar{3}m$ and lattice parameter a = 5.032(3) Å. It is known that the LuH_3 with a face-centered cubic structure is not stable at ambient pressure, but a hexagonal structure with a space group of $P\bar{3}c1$ was reported[18,19]. As shown in Fig. 1**b**, the main reflections of XRD data in our sample SX1 and that downloaded from ref. 1 almost coincide, indicating that they have similar structure. The lattice constant of our sample SX1 is about a = 5.032(3) Å, which is a bit larger than a = 5.0289 Å reported in ref.1, but is very close to 5.033 Å determined previously[19,20] in LuH_2. For checking the lattice constants of our samples more carefully, we did a series of XRD measurements on different samples and found that the lattice constant ranges from 5.029(2) to 5.033(3) Å, see Extended Data Fig.1. Comparing with that in ref. 1, our samples show much less amount of impurities. Therefore, according to our XRD data, we obtained the compounds which have almost the same structure as that reported in ref. 1.

The energy dispersive X-ray spectroscopy (EDS) is used to analyze the element composition in the sample. The inset (left-hand side) in Fig. 1**c** displays a SEM image of $LuH_{2\pm x}N_y$ with randomly measured 10 spots marked by the black crosses. The compositions of nitrogen at these spots are given in the Extended Data Table I. The typical EDS of spot 1 is shown in the main panel of Fig. 1**c**, a weak peak from nitrogen can be identified. The right-hand side inset of Fig. 1**c** shows the spatial distribution of nitrogen, it looks wide-spreading in the whole area, but locally inhomogeneous. Since it is impossible to detect the hydrogen atoms by EDS, while XRD shows that the structure is quite consistent with LuH_2, we define the chemical formula of our samples as $LuH_{2\pm x}N_y$. Figure 1**d** displays the temperature dependence of resistivity (ρ-T) for three samples of $LuH_{2\pm x}N_y$ at ambient pressure. All samples show a metallic behavior down to 2 K. The magnetization was measured for the sample at 10 Oe in the zero-field-cooling (ZFC) and field-cooling (FC) modes. The signal is positive and generally very small, see Extended Data Fig.2.

Raman spectroscopy

We also collected Raman spectra of our $LuH_{2\pm x}N_y$ samples at ambient pressure by using two different instruments both with 532 nm laser excitations. We name these instruments as Raman spectrometer #1 and #2 (see Methods). The Raman spectra measured on three of our samples at ambient pressure are displayed in Fig. 2**a**, the data from ref.1 is shown together for comparison (red curve). The Raman spectra of our samples (SR1-SR3) almost coincide with each other, indicating the uniform crystallinity. Moreover, the band positions of Raman spectra at around 150 cm^{-1}, 190 cm^{-1}, 250 cm^{-1}, and 1200 cm^{-1} (as shown by the dashed lines in Fig. 2**a**) in our samples are highly consistent with that reported by Dasenbrock-Gammon *et al.*[1]. The good consistency on Raman spectrum indicates that our samples are very similar to that reported in ref. 1. We also notice that the spectra collected by using Raman spectrometer #1 on samples SR1 and SR2 below 140 cm^{-1} deviate from that in ref. 1. In their work, the authors observed only one peak in the range from 100 to 140 cm^{-1}, but in our samples SR1 and SR2, there exist several tiny peaks. After taking a careful check on our Raman spectrometer #1, we find that these tiny peaks below 140 $cm^{-1}$are extrinsic and due to the instrument (see Extended Data Fig.3). To further prove that, we used Raman spectrometer #2 to measure on another sample (SR3), which is shown as the green curve in Fig. 2**a**. We can see that the Raman spectrum of sample SR3 is very similar to that reported in ref. 1. Unfortunately, the Raman spectrometer #2 is not suitable for measurements involving a high pressure cell due to the limitation by its objective lens with a short working distance.

Figure 2**b** shows the Raman spectrum of the $LuH_{2\pm x}N_y$ sample (SR1) under various pressures up to 33.4 GPa. Because the Raman band of 1200 cm^{-1} overlaps with the characteristic band of diamond anvils under high pressures, and the one at around 190 cm^{-1} is rather weak, we only focus on the two bands at around 146 cm^{-1} and 250 cm^{-1}. Upon compression, these two Raman bands shift to higher wavenumbers, suggesting a sizeable change of interatomic interaction with pressure. We also conducted an independent control experiment up to 26.6 GPa for another $LuH_{2\pm x}N_y$ sample (SR2), see Extended Data Fig.4. Both sets of data show good agreement with each other.

We then extracted the wavenumbers of these two bands in the Raman spectra under different pressures, and summarized the pressure-dependent band positions in Fig. 2**c**. It is found that the frequencies of Raman bands at around 146 cm^{-1} and 250 cm^{-1} show a continuous increase with increasing pressure. With careful analysis of the data, we found that the slope of the two curves changes obviously around 10 GPa, as shown by the diversion from the red solid lines. Then there is another slight change at around 20 GPa. As we know, in ref. 1, the abnormal changes of Raman band shift under pressure were correlated with three distinct phases. The anomalous Raman band shifts of our samples under high pressures seem to be consistent with that reported by Dasenbrock-Gammon *et al.*[1], except for different thresholds for pressure at which the slope-change occurs. We want to emphasize that these slope-changes are not necessarily associated with three distinct phases, rather the fact that all phonons are unharmonic, and they tend to react to compression more steeply for a low pressure, and less steeply for a high pressure.

Resistance and colors at high pressures

Figure 3**a**, **b** show the temperature dependence of resistance from 10 to 350 K under various pressures. The resistance at room temperature progressively decreases with the increase of pressure up to 6.3 GPa. The temperature dependent resistance *R*(T) curve shows a universal hump structure around 300 K, and such feature becomes weaker for higher pressures. This hump reflects a metal to semiconductor transition, which may share the same origin as that observed in hydrides of many other rare-earth elements[21, 22]. To check whether the decrease in resistance around room temperature is related to a possible superconducting transition, we have also measured *R*(T) curves of $LuH_{2\pm x}N_y$ at various magnetic fields under a pressure of 1.6 GPa. As we can see from Fig. 3**c**, the resistance under magnetic fields exhibits a non-systematic evolution and does not show any drifting to lower temperatures as expected for a superconductor when a magnetic field is applied.

One of the most surprising phenomena reported in ref. 1 is the color change from dark-blue to pink, and red with increasing pressure. And the near-ambient superconductivity was claimed in the state with the pink color. We also tried to see this color change in our samples with pressures up to 5.2 GPa (Extended Data Fig. 5), but the dark-blue color was maintained. The pressure threshold for the color change seems to be sample dependent, in the nitrogen-free[23, 24] or nitrogen doped samples[25, 26]. Thus we tried another run of optical measurements with pressures up to 41 GPa, now the color change can be clearly visualized. As shown in Fig. 4**a**, the color gradually changes from dark-blue to violet, and then to pink-red, the crossover from dark-blue to pink-red occurs in the region from about 11 GPa to about 21 GPa, then the color stays as pink-red. A general chart for the correlation between the color change and pressure for different samples is shown in Extended Data Fig. 6. We found that the pressure region of the color change was pretty consistent with the Raman band-shift anomaly shown in Fig. 2**c**. Although there is a recent literature on photochromism of $LnH_{2+x}O_y$ (*Ln* = lanthanide element)[27], which suggests that this effect may lead to the pink color, however, we would argue that this is not the reason for the pink-red color in our samples since it gradually emerges with increase of pressure, and the pink-red color appears almost in the whole sample under a high pressure. This color change may be explained by the shift of the plasma edge of a metal[24] when it has a low charge carrier density; the latter can be easily tuned by pressure in systems containing shallow bands. Given the color change from dark-blue to pink-red, it is curious to know whether the claimed superconductivity in ref. 1 can be found in this high pressure range, especially with a pink-red color.

We then carried out a new run of measurements on resistivity from 0.4 to 40.1 GPa, the data are shown in Fig. 4**b**. One can clearly see that the general behavior is metallic for the states under all pressures. We also measured the temperature dependent resistance under 15.8 GPa at three different magnetic fields (0, 50, 90 kOe), and found a negative magnetoresistance, which contradicts to the expectation for a superconducting state, see Extended Data Fig. 7. Thus we can safely conclude that no superconductivity is observed under pressures below 40.1 GPa and above 2 K from resistance measurements.

Magnetic moments under high pressures

To check whether there is a diamagnetic signal due to the Meissner effect of the possible superconductivity in our as-grown samples, we measured temperature dependent DC magnetization *M*(T) curves of $LuH_{2\pm x}N_y$ with pressures of 1 GPa and 2.1 GPa. The sample volume for the high pressure measurement is about 0.037 mm^3. The *M*(T) curves at 60 Oe (the same field used in ref.1) under different pressures are shown in Fig. 5**a**, **b**. The magnetic moment increases with decreasing temperature and do not show a sudden drop behavior. Furthermore, due to the background signal of the magnetization measurement device (Honest Machinery Designer, abbreviated as HMD), the values of the total magnetic moment are negative in the whole measured temperature region. In order to get the magnetization signal purely from the sample, we also measured the background signal of the HMD cell at 60 Oe. The data of background signal are presented in Extended Data Fig.8. The net magnetic moments after removing the related background are shown in the insets of Fig. 5**a** and 5**b**. One can see that the net signal of magnetic moment is positive and very weak with a roughly flat feature in the temperature region from 100 to 320 K. The inset of Fig. 5**c** displays the isothermal magnetization *M*(H) curves for $LuH_{2\pm x}N_y$ at 100 K under pressures of 1 GPa (open squares) and 2.1 GPa (open circles). The *M*(H) curve shows a roughly linear behavior with a negative slope from 0 to 6,000 Oe, which is due to the background. To prove that, we have measured one *M*(H) curve at 320 K under 2.1 GPa (up triangle), and one curve at 100 K for the empty HMD cell (solid square). In the main panel of Fig. 5**c**, we show the net *M*(H) curves after subtracting related backgrounds. It is clear that all net *M*(H) curves exhibit a roughly linear behavior with a positive correlation. This corresponds to a possible paramagnetic behavior. We also conducted a new run for magnetization measurement on another $LuH_{2\pm x}N_y$ sample up to 4.5 GPa, see Extended Data Fig.9. The same HMD cell was successfully used to detect a clear superconducting transition in Bi samples before[28]. To prove that this setup is equally sensitive to detect a superconducting phase in the high temperature region, we carried out magnetization measurements on a superconducting sample $(Cu,C)Ba_2Ca_3Cu_4O_{12}$ ($T_c \approx 112$ K)[29,30], the data are shown in Fig. 5**d**. One can see that the signal is negative and huge compared with $LuH_{2\pm x}N_y$. Our magnetization measurements with the data of either temperature dependence or the isothermal magnetization curves all show that there is no any trace of near-ambient superconductivity in $LuH_{2\pm x}N_y$. The absence of near-ambient superconductivity in nitrogen doped lutetium hydrides is supported by recent theoretical calculations[31-34].

In summary, we have successfully synthesized the N-doped lutetium hydrides $LuH_{2\pm x}N_y$ with a dark-blue color. Although our synthesis method is different, the XRD and Raman spectroscopy confirmed that our samples have a similar structure as the main phase reported in ref. 1 with a slight difference of lattice constant. Meanwhile, the existence of nitrogen in our samples is also confirmed by EDS analysis. We also visualized a color change from dark-blue to violet, and pink-red upon applying high pressures, although the threshold pressures for the color change are higher than that in ref. 1. Our resistivity measurements show the absence of superconductivity in $LuH_{2\pm x}N_y$ under pressures up to 40.1 GPa with all different colors down to 2 K. The magnetization measurements further prove that no superconductivity exists in $LuH_{2\pm x}N_y$ above 100 K under near-ambient pressures.

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Methods

Sample preparation and characterization. We synthesized polycrystalline samples of $LuH_{2\pm x}N_y$ using a piston-cylinder type high pressure apparatus (LP 1000-540/50, Max Voggenreiter). The NH_4Cl and excessive CaH_2 were used as the source of nitrogen and hydrogen, according to the chemical reaction equation written as $2NH_4Cl + CaH_2 \rightarrow CaCl_2 + 2NH_3 + H_2$. The NH_4Cl (Alfa Aesar 99.99%) was mixed well with CaH_2 (Alfa Aesar 98%) in a molar ratio of 2:8 and pressed into a tablet. Then, the tablet made by

Lu pieces (purity 99%, Grirem Advanced Materials Co. Ltd.) with silver color were separated from the tablet of NH_4Cl+CaH_2 by a BN pellet and sealed into a gold capsule. The Lu pellet in each sintering weighs about 100 mg. Then the gold capsule was placed in a BN capsule and heated up to 300-350°C and held for 10 hours under 2 GPa. Finally, we find that the Lu tablet turns into a new form composed by two well-separated different regions with dark-blue and silver colors, respectively; the dark-blue region corresponds to the $LuH_{2\pm x}N_y$ phase.

The X-ray diffraction (XRD) measurements were performed on a Bruker *D8* Advanced diffractometer with the CuK_α radiation. The Rietveld refinements were done by using the software[35] of *TOPAS4.2*. The scanning electron microscope (SEM) photograph and the energy dispersive X-ray microanalysis spectrum were obtained by Phenom ProX (Phenom) at an accelerating voltage of 15 kV. Unpolarized Raman-scattering experiments were performed using two instruments at room temperature both with a 532 nm laser excitation line, one is a Raman spectroscopy system (LabRAM HR Evolution Horiba Jobin Yvon), the other one is a home built confocal microscopy setup in the back-scattering geometry in which the scattered light was directed through Bragg notch filters. For clarity, we name the first Raman system as Raman spectrometer #1, and the second Raman system as Raman spectrometer #2. Prior to the measurements, both systems were calibrated for wavenumbers by following the instrument instructions. To get valid data in the low wavenumber region (below 140 cm^{-1}), we used Raman spectrometer #2 for the Raman scattering measurement on a new sample (SR3) placed in vacuum. By the way, before the measurement on the sample SR3, we checked the

Raman spectrometer #2 without a sample, and find a smooth background without any band like features in the low wavenumber region. For the measurements using Raman spectrometer #1 and #2, the laser power was 7.5 and 4 mW, the collection time was 60 and 120 seconds, respectively, and all spectra were measured two times to check reproducibility. For high pressure Raman spectra measurements, two runs of experiments were performed on Raman spectrometer #1 by using a diamond anvil cell (DAC) with T301 steel or rhenium as gasket and methanol/ethanol/water as pressure medium.

Physical property measurements at ambient and high pressures. Temperature dependent resistivity/resistance measurements under ambient and high pressure were carried out with a physical property measurement system (PPMS-9T, Quantum Design). The high pressure was generated by a DAC made of BeCu alloy with two opposing anvils. A four-probe van der Pauw method with platinum foil as electrodes was applied for resistance measurements. The DC magnetization measurements were performed with a SQUID-VSM-7T (Quantum Design). The DC magnetic moment measurements at high pressures were accomplished by using the DAC (attachment to a PPMS) designed by the Honest Machinery Designer's office (HMD). The sample is loaded in a hole in the middle of the gasket made of BeCu which needs pre-pressurization before high-pressure measurements. The gasket is made by BeCu. The anvils with beveled culet size of 400 μm and 600 μm were used to generate high pressures. NaCl and Daphne 7373 were used as the pressure transmitting medium during the resistive and magnetic susceptibility measurements, respectively. For optical measurements, we used KBr as the pressure transmitting medium. The pressure was measured at room temperature using the ruby fluorescence method[36].

Data availability statement

All data needed to evaluate the conclusions in the paper are present in the paper. Source data are provided with this paper.

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Author contributions

The sample growth and SEM/EDS analysis were made by X.M., X.Y.Z., C.P.H., B.Z. and H.H.W. The XRD data were collected by Y.C.L. and X.M. The resistivity and magnetization were measured by Q.L. and Y.J.Z. The photos were taken by H.Y. The Raman spectra were collected and analyzed by Q.L., T.H.H., G. L., X.X. and J.S. All authors joined the analysis and agreed to publish the data. The manuscript was written by Q.L., X.Y.Z. and H.H.W. H.H.W. conceived and supervised the whole research.

Author statement about reproducibility and control experiments

We have conducted multiple kinds of experiments on more than 30 samples: 7 specimens measured for resistivity at ambient pressure; 5 specimens for resistivity under high pressures; 2 specimens for magnetization measurements at ambient pressure; 3 specimens for magnetization measurements under high pressures; 6 specimens for XRD measurements; 3 runs (specimens) for the Raman spectroscopy measurements; 5 runs (specimens) for optical image measurements; 8 specimens for SEM/EDS measurements.

Competing interests

The authors declare that they have no competing interests.

Main Figure Legends

Fig. 1 | Structure, composition and transport measurements for $LuH_{2\pm x}N_y$. a, Powder X-ray diffraction patterns of the $LuH_{2\pm x}N_y$ and Rietveld fitting curves (red lines) to the data. The tiny reflection at 32.2° can be indexed to the phase of Lu_2O_3. The inset shows the picture of $LuH_{2\pm x}N_y$ samples which exhibit a dark-blue color. **b,** The comparison of XRD patterns with normalization between our sample SX1 and that downloaded from ref. 1. The inset shows an enlarged view with 2θ from 29° to 37° for two of our samples (SX1 and SX5) and that from ref. 1. The main reflections of our samples look sharper than that in ref. 1. **c,** SEM images and typical EDS of spot 1. Inset (left-hand side) shows the image with ten spots measured by point-wise measurement of EDS; the inset on the right-hand side shows the mapping image for nitrogen elements. It is clear that the nitrogen distribution is not uniform in the sample, and it remains to be resolved at which positions these nitrogen atoms locate in the lattice. **d,** Temperature dependence of resistivity for three $LuH_{2\pm x}N_y$ samples under ambient pressure. Inset shows the image of the measured sample (S1) with electrodes attached at ambient pressure. The error bar for determining resistivity is about ±10%. The ρ-T curves are roughly linear from 60 to 300 K and exhibit a power-law temperature dependence at lower temperatures (2-60 K). The red solid lines represent the fitting curves using the formula $\rho = \rho_0 + AT^n$ from 2 to 60 K, with ρ_0 the residual resistivity, n and A are the fitting parameters. The fitting yields n = 2.89, 2.71 for S2 and S3, respectively.

Fig. 2 | Raman spectra of $LuH_{2\pm x}N_y$. a, Typical Raman spectra collected at ambient pressure for three samples (black, blue and green curves), and the data of N-doped Lu hydride from ref. 1 (red curve) for comparison. The samples are labeled as SR1, SR2 and SR3, respectively. The tiny peaks of SR1 and SR2 below 140 cm^{-1} are shown to be originated from the background signal of the Raman spectrometer #1 (See Extended Fig.3). The band positions in the spectrum below 300 cm^{-1} have slightly smaller wavenumbers compared with that in ref. 1, indicating that the lattice constant of our sample is slightly larger. The results are also consistent with the lattice parameters obtained from X-ray diffraction. Such a slight variation may be attributed to the different hydrogen/nitrogen concentrations in different samples. **b,** Raman spectra were collected under high pressures by using Raman spectrometer #1 with methanol/ethanol as the pressure medium. **c,** The evolution of band positions of Raman spectra under pressures, the two curves correspond to the bands as indicated in (**b**) by red arrows. The red lines are guides for eyes to show the change of slopes.

Fig. 3 | Temperature-dependent resistance for $LuH_{2\pm x}N_y$ at different pressures up to 6.3 GPa. a, Temperature dependence of the electrical resistance of $LuH_{2\pm x}N_y$ from 10 to 350 K with pressures up to 6.3 GPa (DAC filled with polycrystalline pieces). The weak upturn of *R*(T) curve in low temperature region may be induced by the hopping of electrons through a large inter-grain spacing or grain boundaries when the grains are compacted loosely in the DAC space. This explanation can get a support from the weakening and absence of this low temperature upturn when the pressure becomes higher. **b,** Temperature dependence of the electrical resistance of $LuH_{2\pm x}N_y$ up to 2.7 GPa for another run with the DAC filled with powder of the sample. Now we can see that the low-temperature upturn disappears. **c,** Temperature dependence of the electrical resistance of $LuH_{2\pm x}N_y$ measured at different magnetic fields up to 90 kOe at 1.6 GPa (DAC filled with polycrystalline pieces).

Fig. 4 | Pressure induced color change and evolution of temperature-dependent

resistance for $LuH_{2\pm x}N_y$ at different pressures. a, The optical microscope images of $LuH_{2\pm x}N_y$ at different pressures up to 41 GPa. A color change from dark-blue to violet and pink-red is observed. **b,** Temperature dependence of the electrical resistance of $LuH_{2\pm x}N_y$ from 2 to 350 K with pressures up to 40.1 GPa. In most *R*(T) curves, we can see a metallic behavior from an intermediate temperature all the way down to 2 K, either in the dark-blue or the pink-red states. The *R*(T) curves at low pressures, such as at 0.4 and 1.1 GPa show again the weak upturn in low temperature region, which gradually becomes invisible when the pressure is increased. And there is a resistivity hump in the region around 300 K in the low pressure region.

Fig. 5 | Magnetic properties for $LuH_{2\pm x}N_y$ at different pressures. a, b, Temperature dependence of magnetic moment for $LuH_{2\pm x}N_y$ under pressures of 1 GPa and 2.1 GPa, respectively. Shown in the main panels are raw data. The insets show the corresponding magnetic moments measured in ZFC and FC modes with the background subtracted. **c,** *M(H)* curves with different background signal removed. The inset shows the raw data of *M(H)* curves at 100 K under pressures of 1.0 GPa (open square) and 2.1 GPa (circle), and one curve at 320 K under 2.1 GPa (up triangle), respectively. The *M*(H) curve measured at 100 K for the empty HMD cell is also shown here (solid square). **d,** Temperature dependence of ZFC-FC magnetizations measured on a superconducting sample $(Cu,C)Ba_2Ca_3Cu_4O_{11+\delta}$ (T_c = 112 K) with the same measured volume as that for $LuH_{2\pm x}N_y$ shown in (**a**) and (**b**), and the same HMD setup was used under the same magnetic field (60 Oe). If the phase $LuH_{2\pm x}N_y$ were superconductive, one should observe a diamagnetic signal in the same scale at the same field (60 Oe).

Extended Data Table I | The atomic concentration of nitrogen by EDS analysis at 10 spots of the sample. The average value of nitrogen in atomic ratio over these 10 spots is about 1.2%.

Extended Data Fig. 1 | XRD and Rietveld refinement on other four samples. **a-d,** Powder X-ray diffraction patterns of four samples (SX2-SX5) and Rietveld fitting curves (red lines) to the data. The inset in (**d**) presents the Rietveld fitting results (lattice parameters and molar concentration of $LuH_{2\pm x}N_y$) of five samples (SX1-SX5). The slight difference of the lattice constants may be attributed to the different hydrogen/nitrogen concentrations or the crystallinity in different samples. The Rietveld fitting to these results shows a high purity with the main phase in a molar ratio of about 95%, and are highly consistent with each other.

Extended Data Fig. 2 | Temperature dependence of the magnetic susceptibility for $LuH_{2\pm x}N_y$ at ambient pressure. a, Temperature dependence of magnetic moment for $LuH_{2\pm x}N_y$ (upper part) along with background signal (lower part) measured in an applied field of 10 Oe using both the ZFC and FC modes. **b**, The corresponding magnetic susceptibility $4\pi\chi$ with the background subtracted, for a superconductor we should expect $4\pi\chi$ = -1. In calculating the magnetic susceptibility, we have used a density of 9.22 g/cm^2 quoted for compound LuH_2. The measurements were carried out by using the SQUID-VSM with a vibrating amplitude of 5 mm and frequency of 13.01 Hz.

Extended Data Fig. 3 | Raman spectra collected on Raman spectrometer #1. The black curve (upper one) shows the raw data measured on the $LuH_{2\pm x}N_y$ sample (SR1) using the Raman spectrometer #1, while the orange curve (bottom one) shows the background signal of the instrument without the sample nor the DAC. It is clear that the bands around 106 cm^{-1}, 115 cm^{-1}, 122 cm^{-1}, 129 cm^{-1} and 138 cm^{-1} are originated from the instrument itself.

Extended Data Fig. 4 | Raman spectra of another $LuH_{2\pm x}N_y$ sample (SR2) under different pressures. In this measurement, a rhenium gasket was used. The Raman bands around 146 cm^{-1} and 250 cm^{-1} show continuous increase with increasing pressure. Due to a sizeable Raman signal from the instrument under low wavenumbers, we show only the data above 140 cm^{-1}.

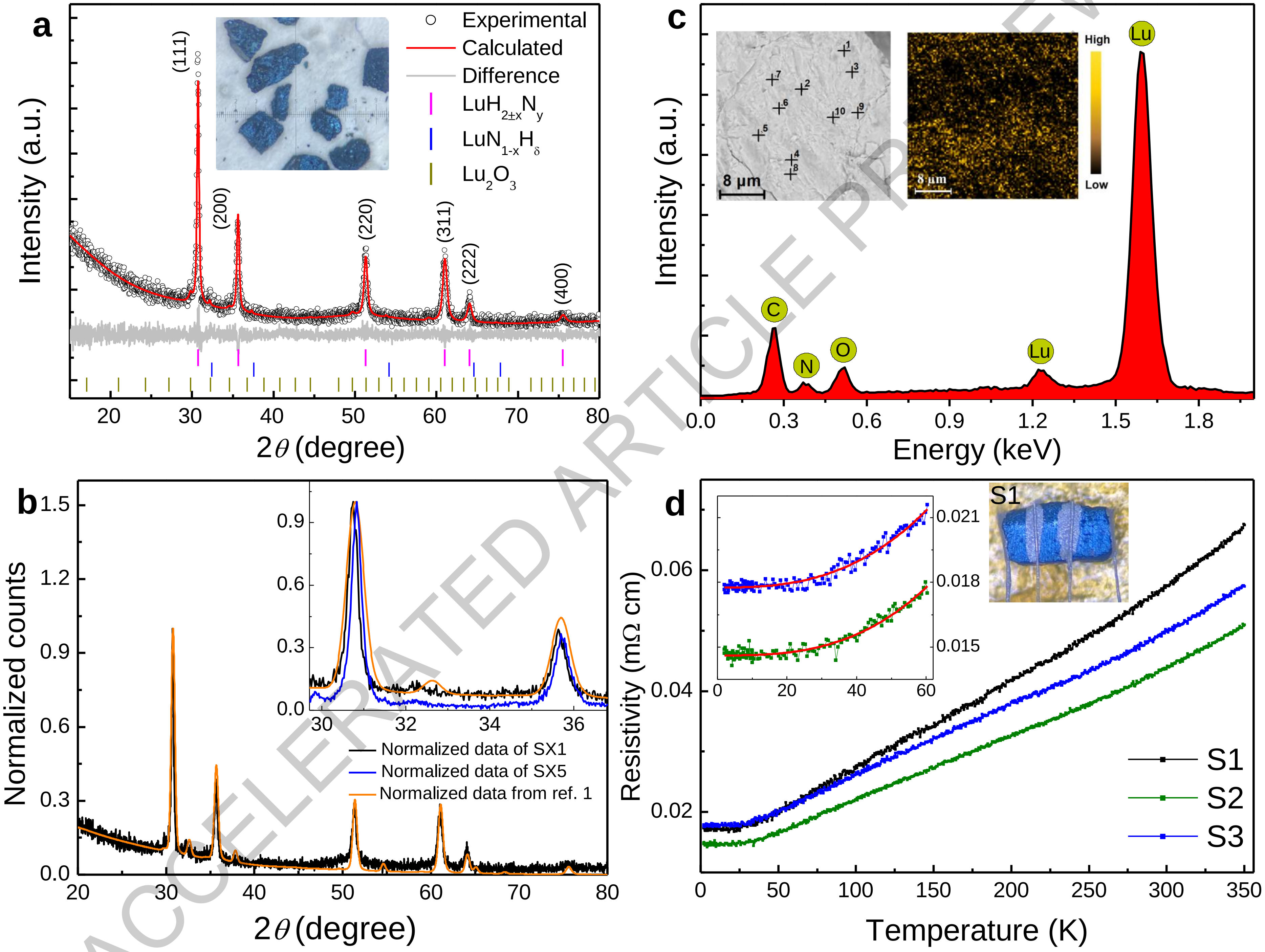
Extended Data Fig. 5 | The optical microscope images of $LuH_{2\pm x}N_y$ at different pressures up to 5.2 GPa. In this run, the sample was directly filled in the DAC chamber without any pressure medium.

Extended Data Fig. 6 | A sketch for pressure dependence of the color change for different samples. The data are collected from Fig. 4 **a** and ref 1, 23, 24, 25, 26.

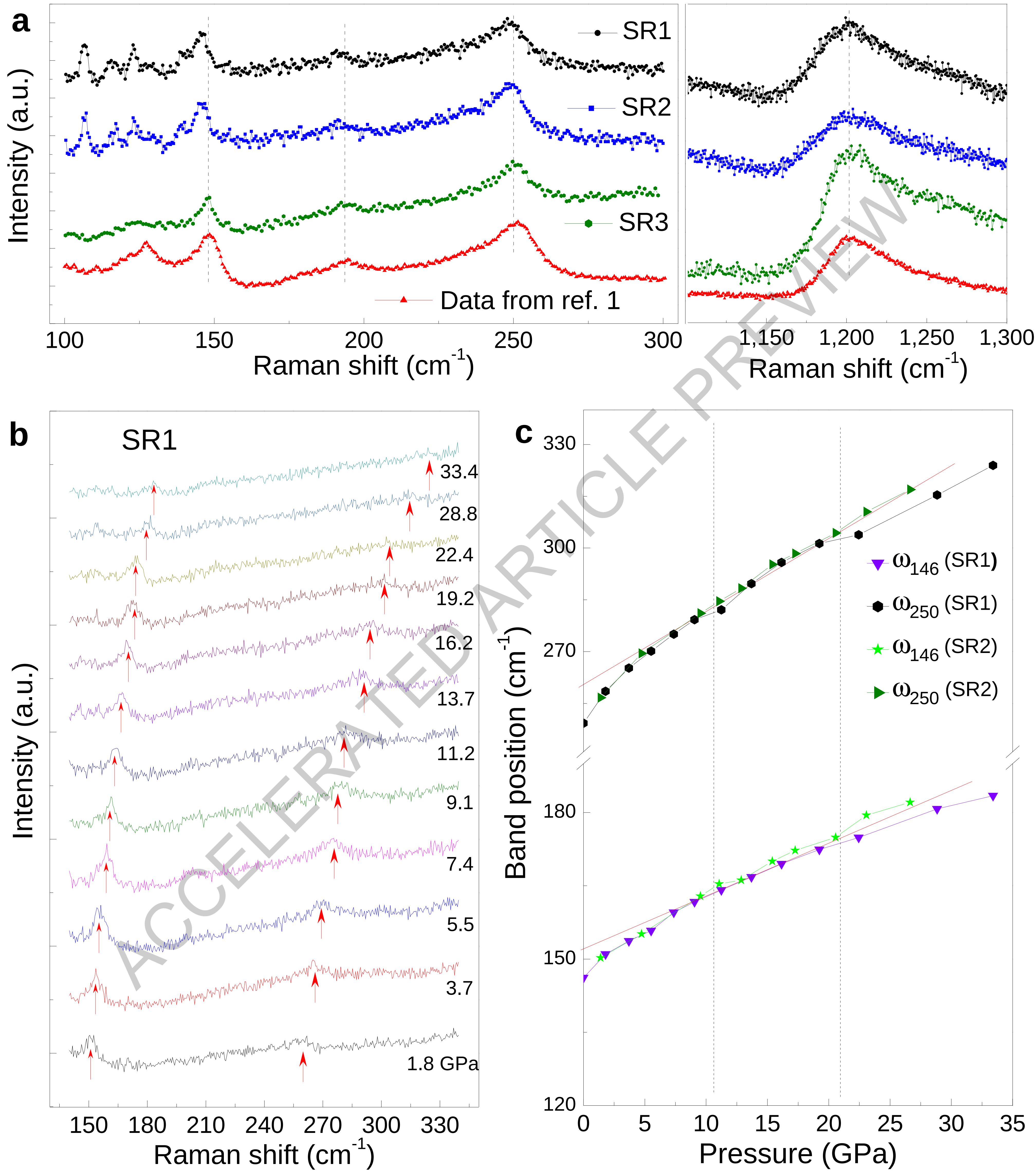
Extended Data Fig. 7 | Temperature dependence of electrical resistance for $LuH_{2\pm x}N_y$. The measurements were conducted under a pressure of 15.8 GPa with various magnetic fields up to 90 kOe. The hump structure around 250-300 K is gradually suppressed by external fields and a negative magnetoresistance is observed. No superconducting signal was detected down to 2 K.

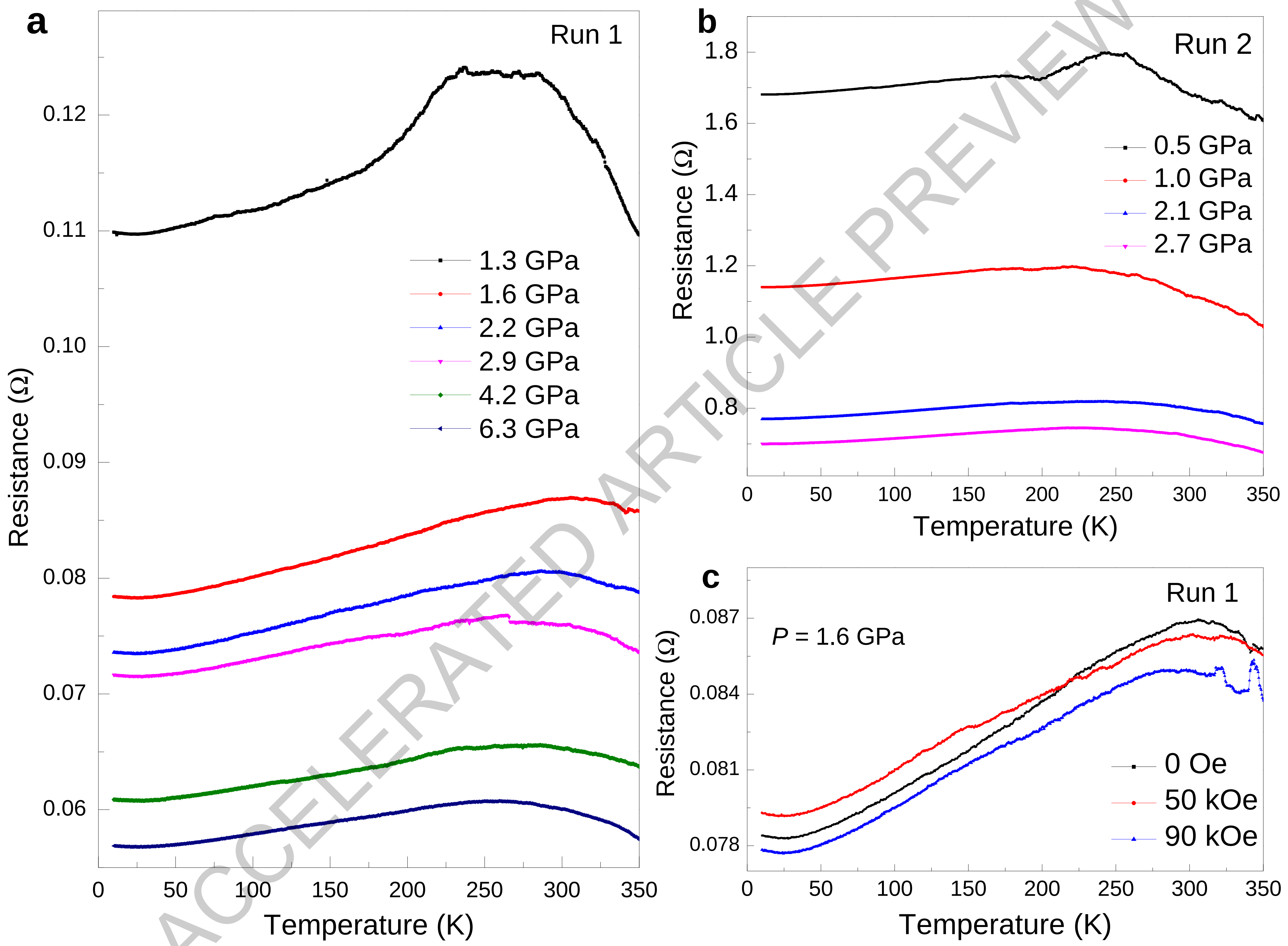
Extended Data Fig. 8 | Temperature dependence of magnetic moment for the empty HMD cell. The applied magnetic field was H = 60 Oe. The ZFC and FC M(T) curves are used as the background signals to obtain the magnetic moment purely from the sample in the DC magnetization measurements.

Extended Data Fig. 9 | Temperature dependence of magnetic moment for $LuH_{2\pm x}N_y$. All curves were measured in an applied field of 60 Oe using both the ZFC and FC modes in run 2 at pressures of **(a)** 1.5 GPa and **(b)** 4.5 GPa. The raw data are shown in the main panels. The insets show the corresponding magnetization with the background signal removed. The magnetic susceptibility for $LuH_{2\pm x}N_y$ is positive in the whole temperature region, and no diamagnetic signal was detected, which is contrary to the existence of superconductivity.

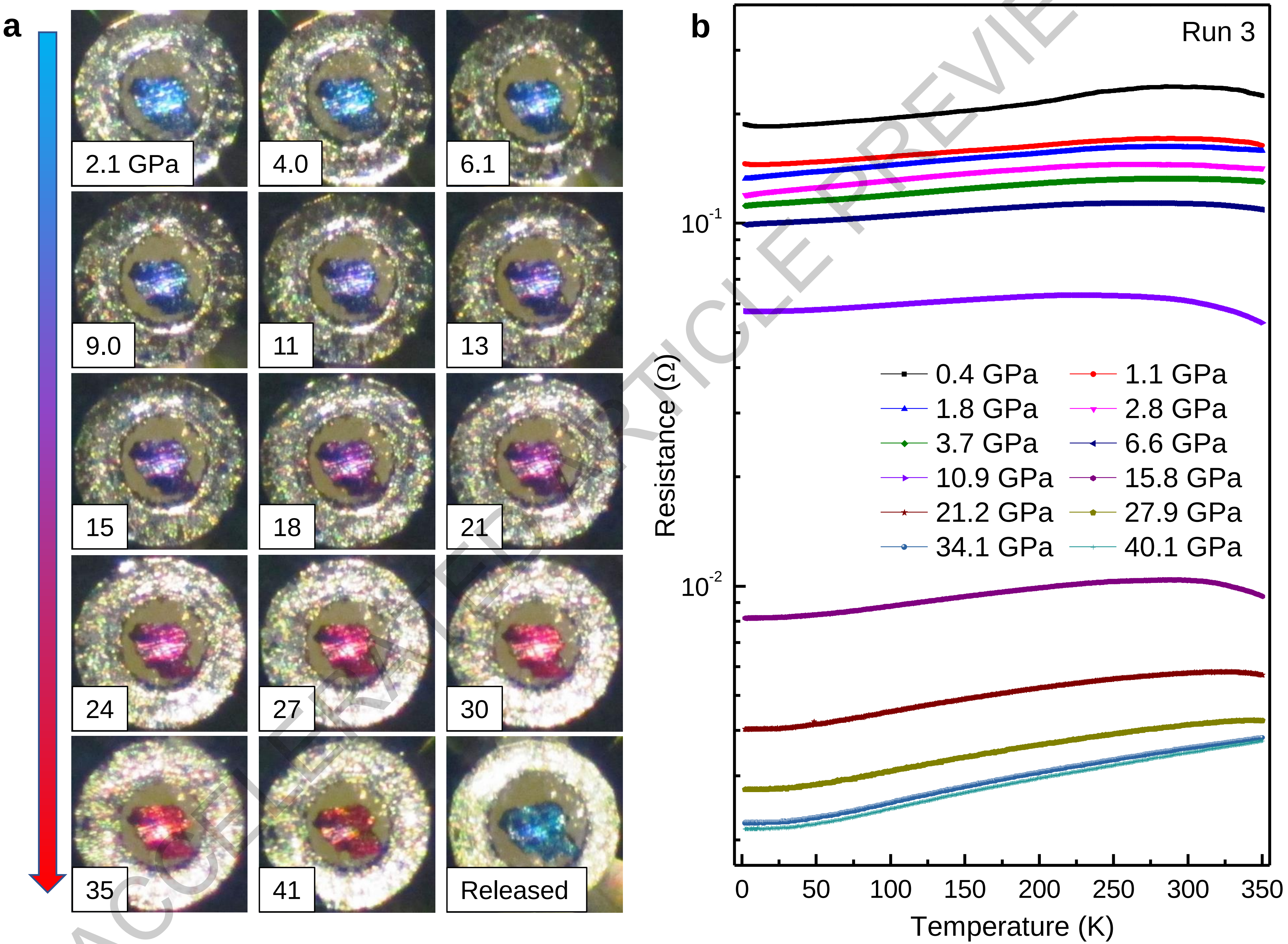


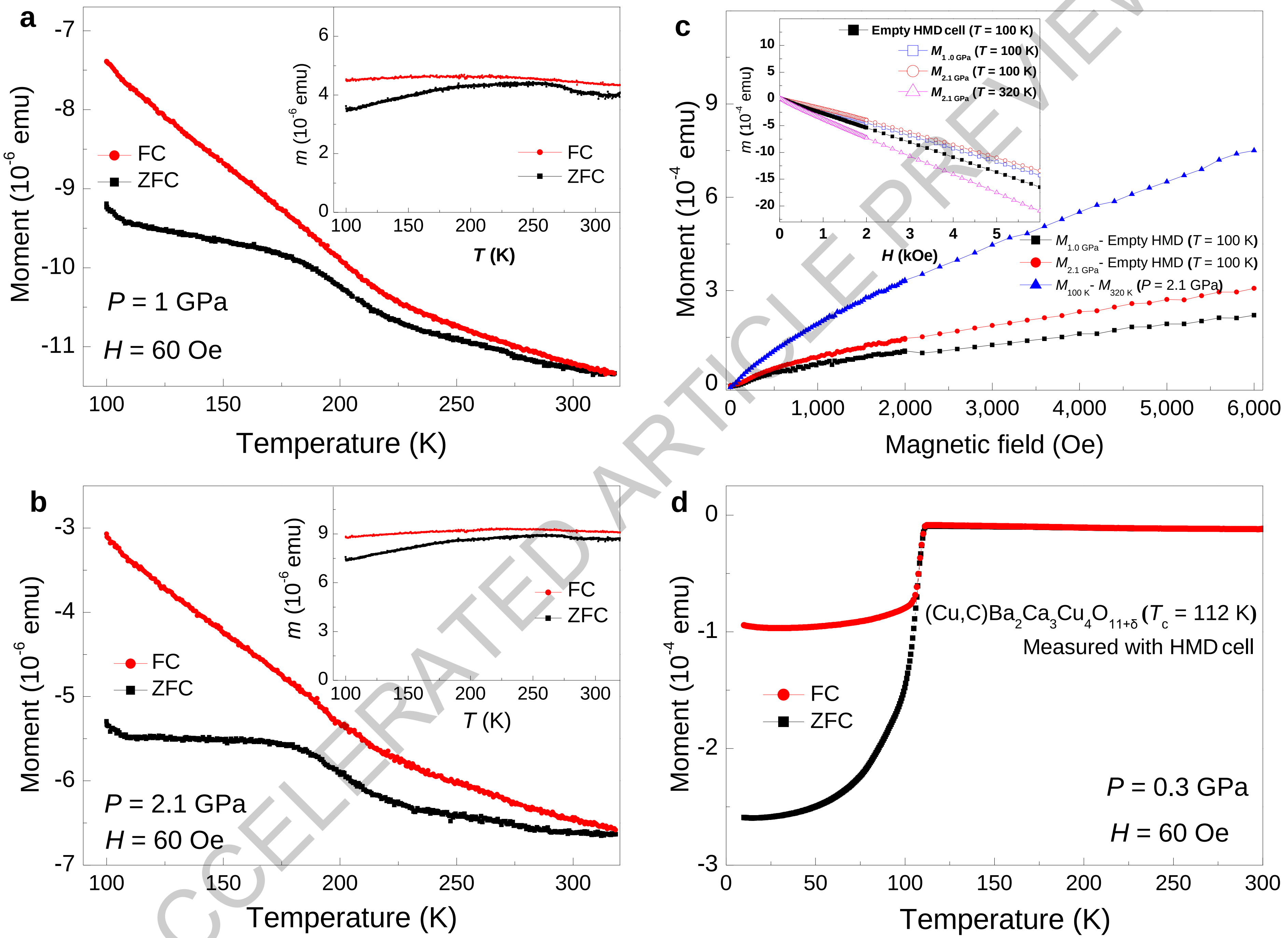
a
Experimental
Calculated
Difference
$LuH_{2\pm x}N_y$
$LuN_{1-x}H_\delta$
Lu_2O_3
(111)
(200)
(220)
(311)
(222)
(400)
Intensity (a.u.)
2θ (degree)
b
Normalized counts
Normalized data of SX1
Normalized data of SX5
Normalized data from ref. 1
2θ (degree)
c
8 μm
High
Low
C
N
O
Lu
Lu
Intensity (a.u.)
Energy (keV)
d
S1
S1
S2
S3
Resistivity (mΩ cm)
Temperature (K)
ACCELERATED ARTICLE PREVIEW

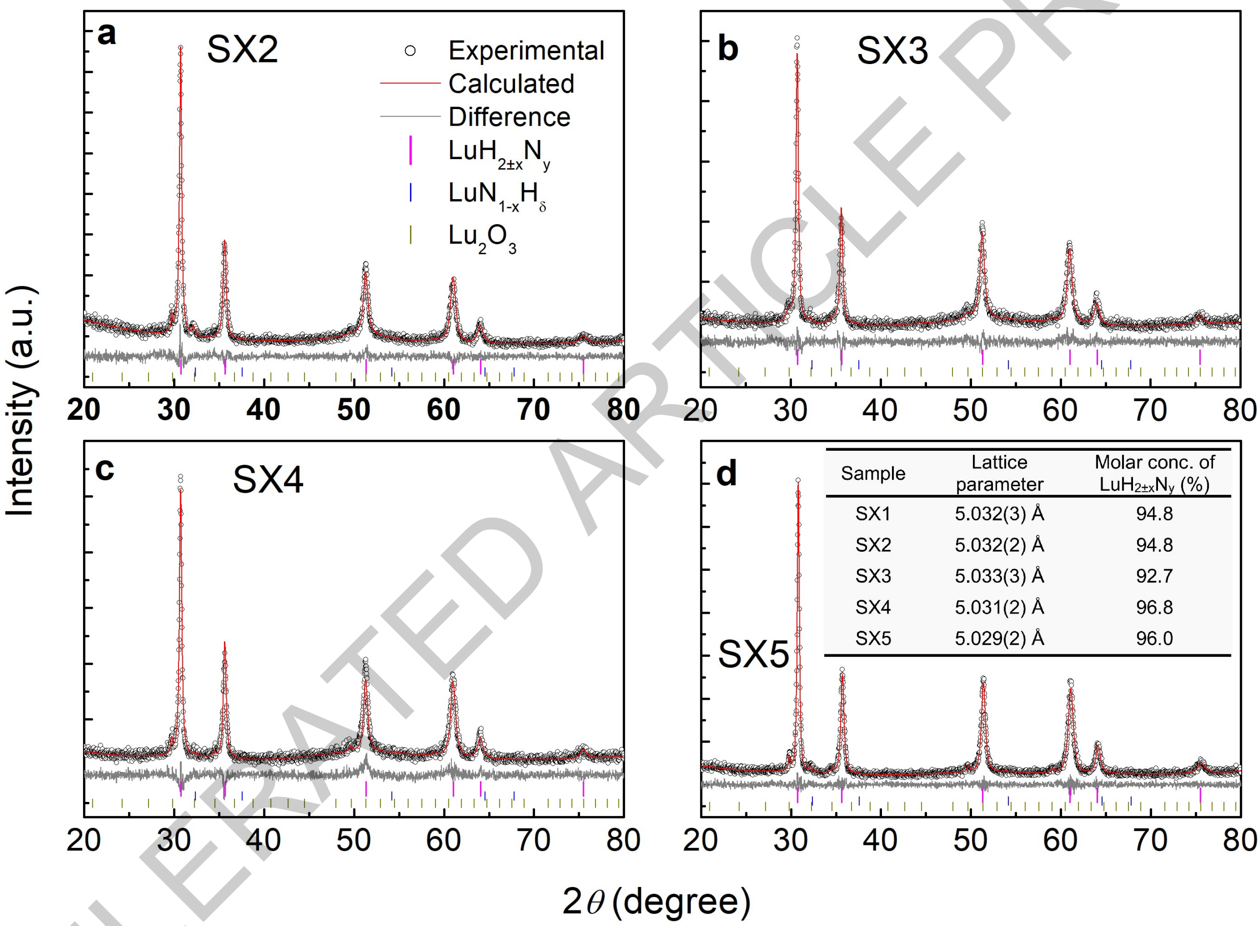

a
SR1
SR2
SR3
Data from ref. 1
Intensity (a.u.)
Raman shift (cm-1)
b
SR1
33.4
28.8
22.4
19.2
16.2
13.7
11.2
9.1
7.4
5.5
3.7
1.8 GPa
c
Band position (cm-1)
Pressure (GPa)
ω146 (SR1)
ω250 (SR1)
ω146 (SR2)
ω250 (SR2)
ACCELERATED ARTICLE PREVIEW



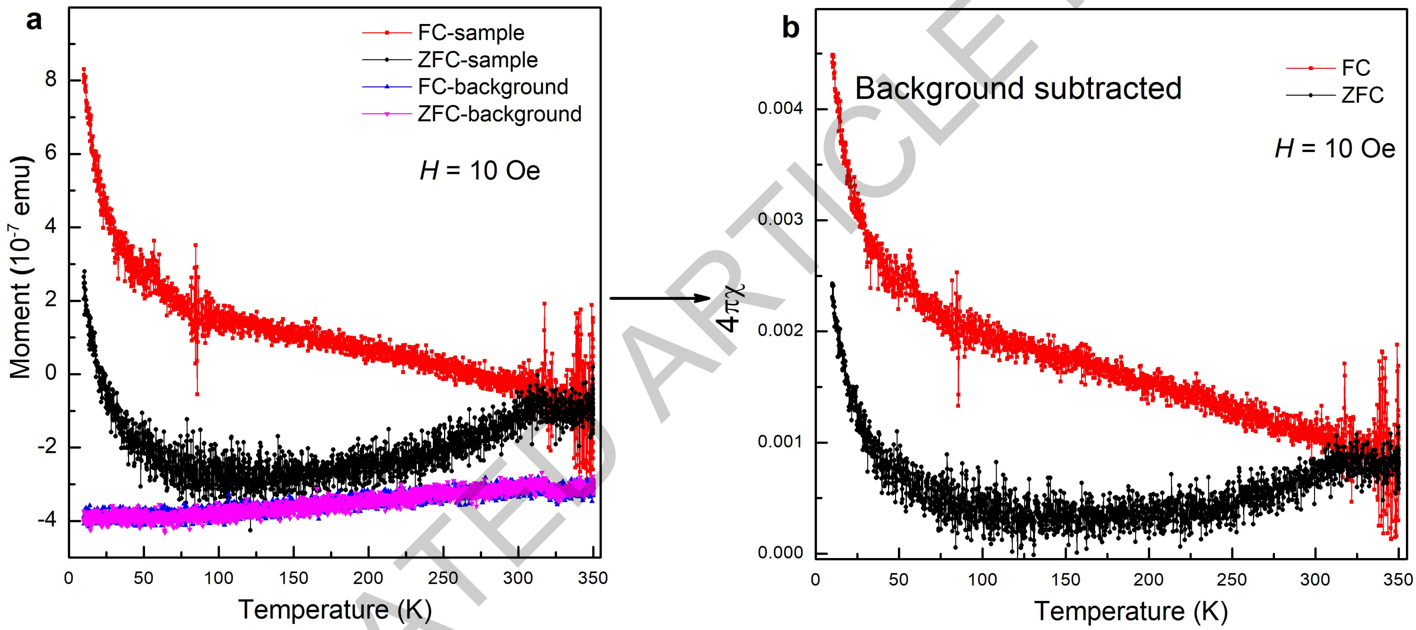
a
Run 1
Resistance (Ω)
Temperature (K)
1.3 GPa
1.6 GPa
2.2 GPa
2.9 GPa
4.2 GPa
6.3 GPa
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0
50
100
150
200
250
300
350
b
Run 2
Resistance (Ω)
Temperature (K)
0.5 GPa
1.0 GPa
2.1 GPa
2.7 GPa
0.8
1.0
1.2
1.4
1.6
1.8
c
Run 1
P = 1.6 GPa
Resistance (Ω)
Temperature (K)
0 Oe
50 kOe
90 kOe
0.078
0.081
0.084
0.087


a
2.1 GPa
4.0
6.1
9.0
11
13
15
18
21
24
27
30
35
41
Released
b
Run 3
Resistance (Ω)
Temperature (K)
0.4 GPa
1.1 GPa
1.8 GPa
2.8 GPa
3.7 GPa
6.6 GPa
10.9 GPa
15.8 GPa
21.2 GPa
27.9 GPa
34.1 GPa
40.1 GPa
10^{-1}
10^{-2}
0
50
100
150
200
250
300
350


a
Moment (10^-6 emu)
-7
-8
-9
-10
-11
FC
ZFC
P = 1 GPa
H = 60 Oe
100
150
200
250
300
Temperature (K)
m (10^-6 emu)
T (K)
b
-3
-4
-5
-6
-7
P = 2.1 GPa
H = 60 Oe
c
Moment (10^-4 emu)
Magnetic field (Oe)
0
1,000
2,000
3,000
4,000
5,000
6,000
Empty HMD cell (T = 100 K)
M1.0 GPa (T = 100 K)
M2.1 GPa (T = 100 K)
M2.1 GPa (T = 320 K)
m (10^-4 emu)
H (kOe)
M1.0 GPa - Empty HMD (T = 100 K)
M2.1 GPa - Empty HMD (T = 100 K)
M100 K - M320 K (P = 2.1 GPa)
d
(Cu,C)Ba2Ca3Cu4O11+δ (Tc = 112 K)
Measured with HMD cell
P = 0.3 GPa
H = 60 Oe
Temperature (K)



Extended Data Fig. 1



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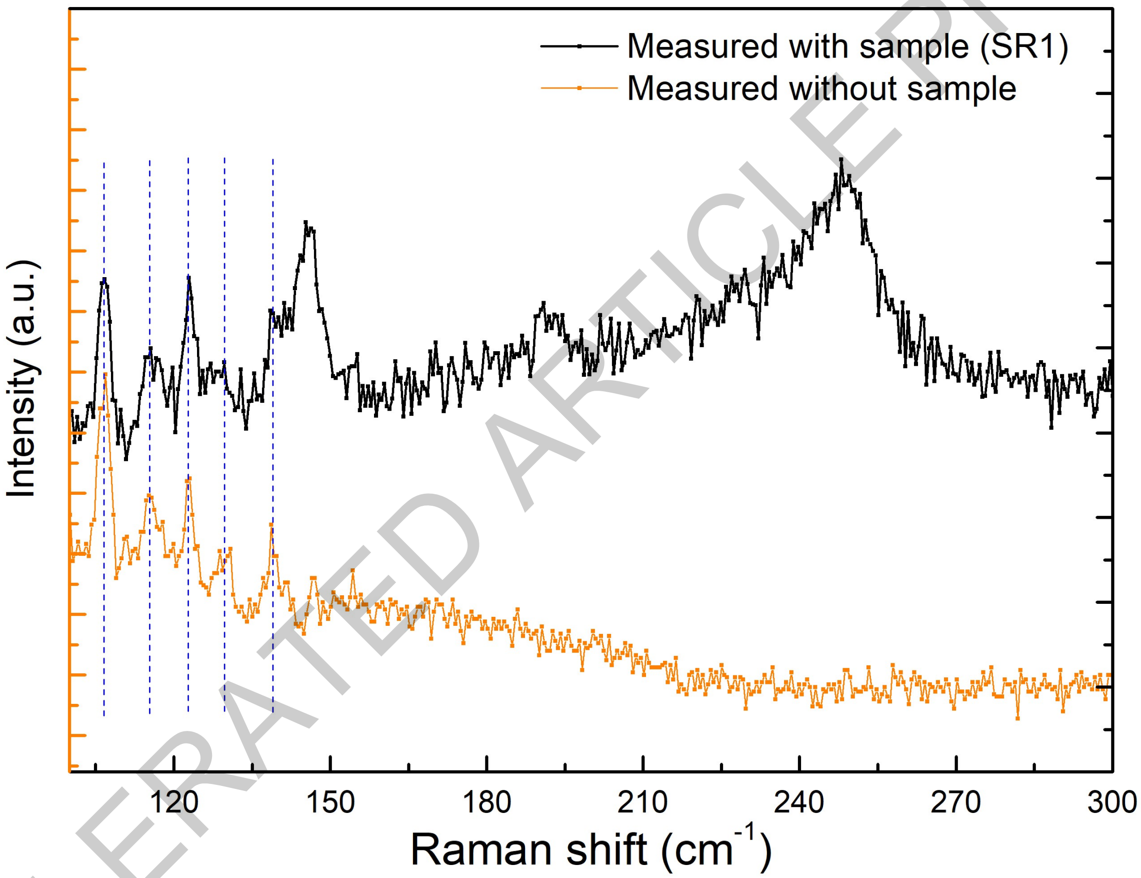
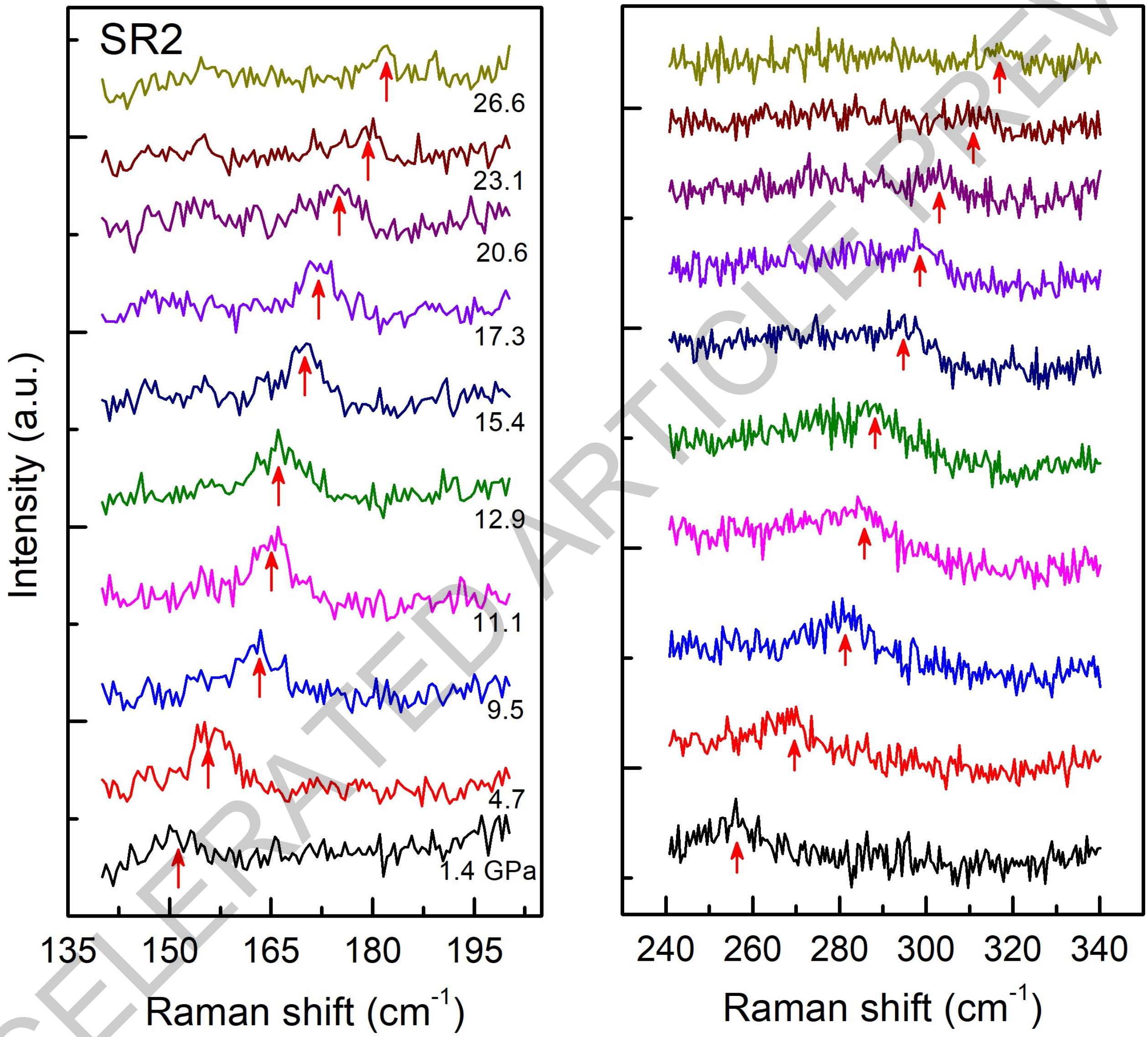
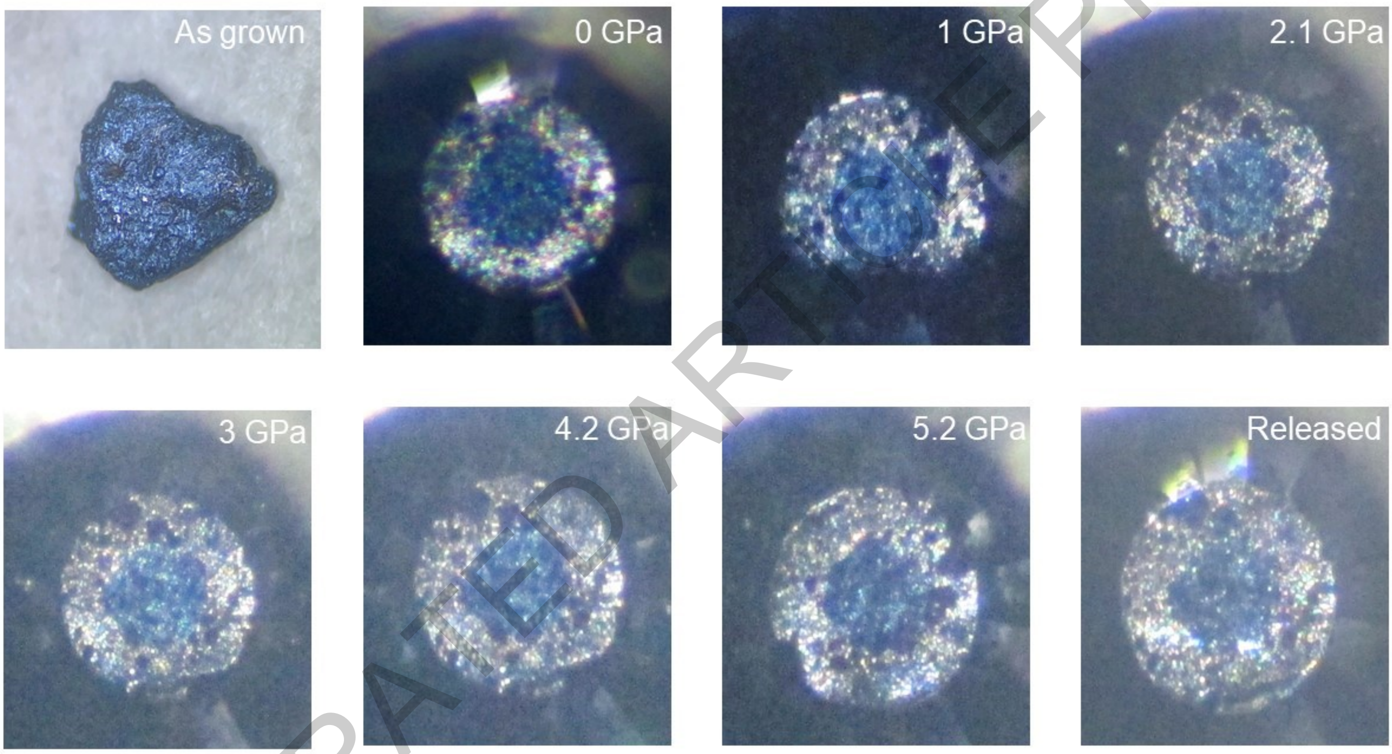


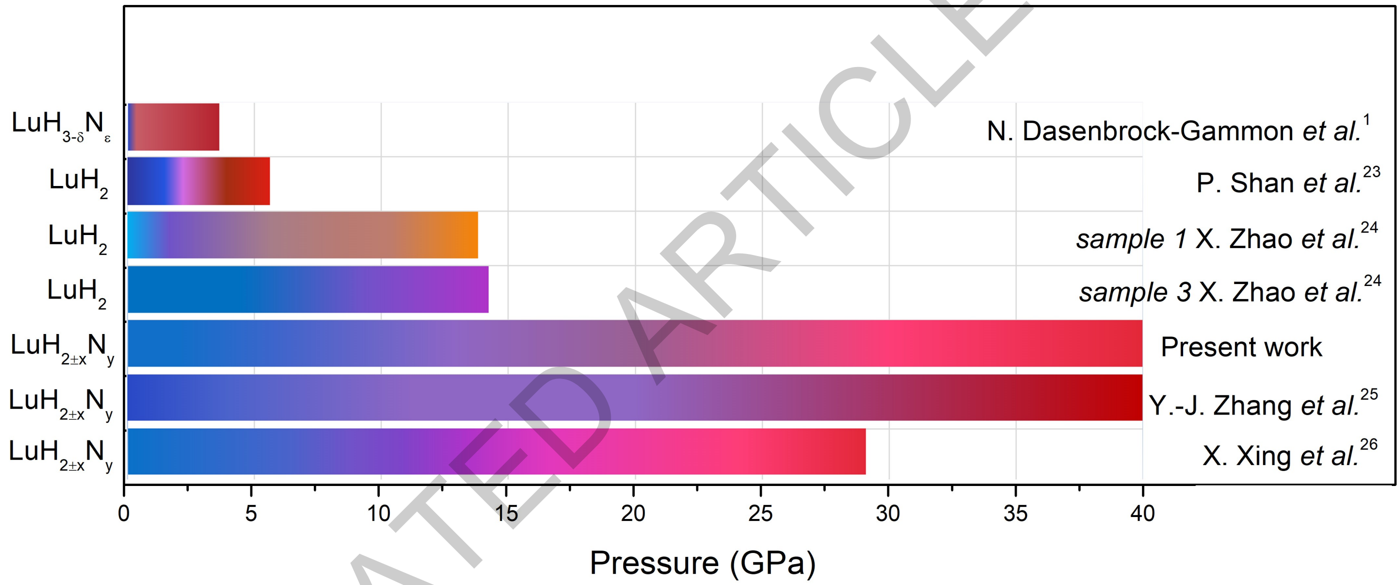
Extended Data Fig. 3



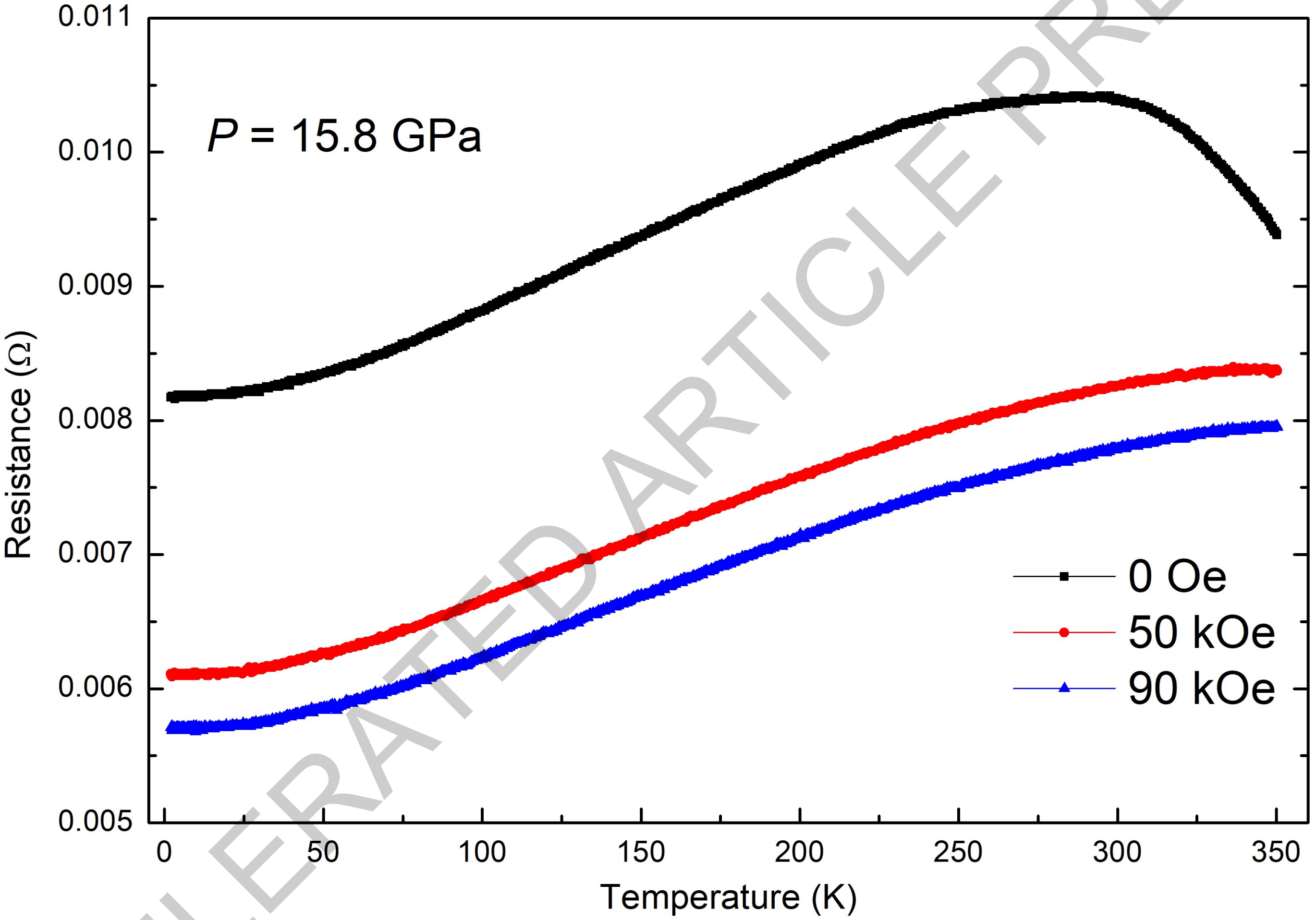
Extended Data Fig. 4



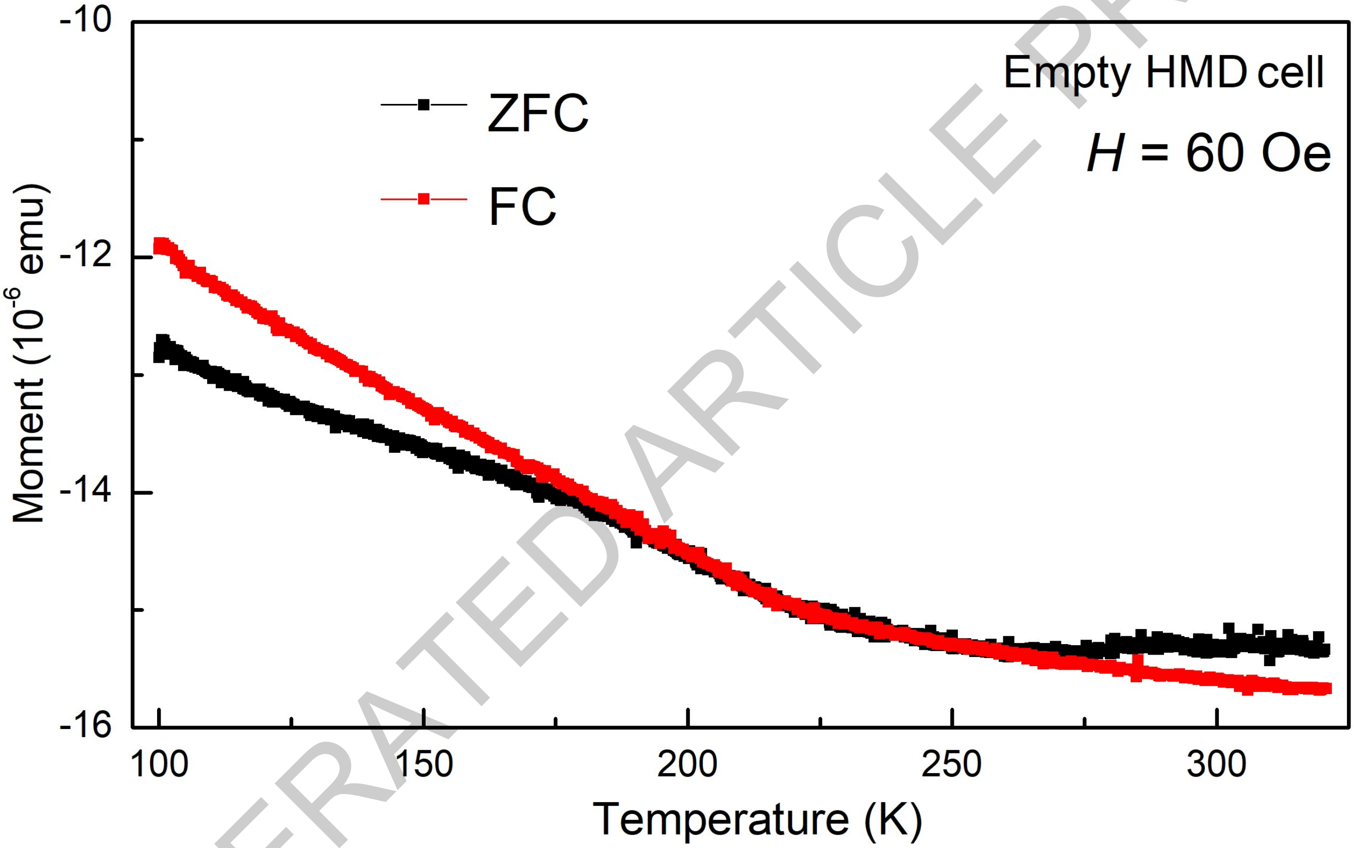
Extended Data Fig. 5



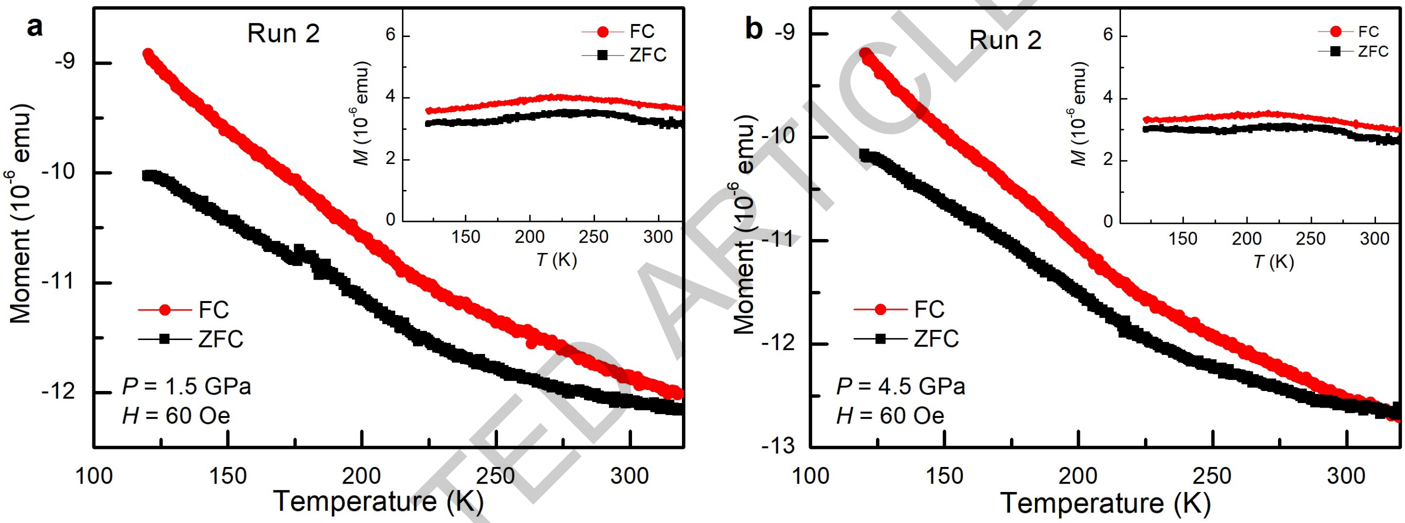
Extended Data Fig. 6



Extended Data Fig. 7



Extended Data Fig. 8



Extended Data Fig. 9

Spot number	Atomic conc. of N (%)
Spot 1	8.26
Spot 4	0.66
Spot 7	1.27
Spot 9	1.78
Other spots	0

Extended Data Table 1