

Evidence for spin-fluctuation-mediated superconductivity in electron-doped cuprates

Corresponding Author: Professor Nigel Hussey

Version 0:

Reviewer comments:

Reviewer #2

(Remarks to the Author)

This manuscript reports a comprehensive magnetotransport study of the electron-doped cuprate $\text{La}_{2-x}\text{Ce}_x\text{CuO}_4$ (LCCO) across the overdoped region of its phase diagram. By combining high-field in-plane resistivity and magnetoresistance measurements with detailed Boltzmann modelling, the authors extract the temperature-, field-, and doping-dependent scattering rate with high precision. A central finding using the Shockley-Chambers Tube Integral Formalism (SCTIF) is the presence of a strongly anisotropic and predominantly T-linear inelastic scattering channel whose magnitude decreases markedly with increasing doping and closely tracks the suppression of T_c . Through a systematic analysis of both magnetoresistance and Hall effect data, including the incorporation of current-vertex corrections (CVC), the authors argue that the dominant scattering mechanism arises from commensurate antiferromagnetic spin fluctuations.

On this basis, the authors establish a clear correlation between the strength of the T-linear scattering term, an effective spin-fluctuation coupling parameter, and the superconducting transition temperature T_c . They conclude that low-energy antiferromagnetic spin fluctuations act as the primary pairing glue in electron-doped cuprates. By contrasting the magnetotransport behaviour of electron- and hole-doped systems, the study suggests that the higher T_c in hole-doped cuprates cannot be explained solely by an enhancement of the same spin-fluctuation mechanism.

The analysis based on the relaxation-time approximation (RTA) is technically sound and carefully executed, and the overall conclusions are convincing. By incorporating CVCs, the authors present a unified framework that consistently accounts for the electrical resistivity, Hall coefficient, and magnetoresistance within a coherent picture. In this respect, the work provides strong support for a Fermi-liquid description in proximity to antiferromagnetism in electron-doped cuprates and represents a significant contribution to the field. While the main results are compelling, several aspects of the analysis would benefit from clarification in the revised manuscript.

[1] In panels h, i, and j of Figure 2, the vertical axis shows $d\rho/dH$ and the horizontal axis shows H/T , with curves from 194 K (yellow) to 8 K (purple). Thinner lines are also present in these panels. The manuscript should state what these thinner lines represent and how they are to be interpreted.

[2] In Eq. (1), a specific functional form for $1/\tau(\phi, T, x)$ is introduced. The physical origin of the T-independent $\tau_{\text{HS}}(\phi)$ term needs to be clarified. Does it represent non-local impurity potential scattering with angular dependence? In the revised manuscript, the functional form of $\tau_{\text{HS}}(\phi)$ is needed to be explained.

[3] In Eq. (1), $\beta(\phi)$ is taken, in the spin-fluctuation scenario, to be proportional to $\sin^2(2\phi \pm \dots)$. The origin of the exponent 2 is not explained. The authors should justify this choice.

[4] The relationship between $\beta(\phi)$ and $\tau_{\text{HS}}(\phi)$ should be clarified. If a common hotspot width is assumed for both terms, the physical justification for this assumption needs to be stated.

[5] The SCTIF formalism is introduced in Eqs. (2) and (3) of the Supplementary Information, but key elements, including the explicit role of the magnetic field, are omitted. Since this formalism underpins the quantitative analysis, the full set of equations actually used in the calculations should be presented.

[6] Extended Data Figure 9 compares magnetoresistance calculated with and without current-vertex corrections (CVCs), but the procedure used to compute the CVC-included magnetoresistance is not described in sufficient detail. Please explain how CVCs are incorporated within the SCTIF framework.

[7] The manuscript should clarify whether the value of τ_{imp} used in Eq. (1) is quantitatively consistent with the experimentally measured residual resistivity shown in Extended Data Figure 1. Demonstrating this consistency would strengthen the internal coherence of the analysis.

Reviewer #3

(Remarks to the Author)

Understanding the temperature dependence of resistivity in high-temperature cuprates is crucial because it lies at the heart of one of the most important unsolved problems in condensed matter physics: the mechanism of high- T_c superconductivity. In general, the temperature-dependent resistivity of cuprates deviates strongly from conventional metallic (Fermi liquid) theory and may signal quantum criticality, pointing toward possible universal limits of strongly correlated quantum matter. Recently, the concept of Planckian dissipation has suggested that the absence of an intrinsic energy scale other than temperature could underlie the linear-in- T resistivity, particularly in the strange metal phase. However, this behavior is far from universal across materials and doping levels. Therefore, a detailed and systematic investigation of the temperature dependence of resistivity (and magnetoresistivity) over a broad doping range is essential.

In this paper, the authors report such a study in the electron-doped cuprate LCCO, using fine doping steps across the entire overdoped region of the phase diagram. The samples are of exceptionally high quality, produced by the University of Maryland group. While the overall resistive and superconducting properties of this sample series were reported previously (Ref. 10), the present work provides a much more in-depth and comprehensive analysis.

One key new insight comes from a semiclassical Boltzmann treatment that incorporates strong anisotropy in the inelastic scattering channel associated with the so-called “hot spots.” Furthermore, through modeling of the Hall conductivity, the authors identify the location of these hot spots along the antiferromagnetic Brillouin zone boundary. This enables them to quantify the temperature-dependent anisotropic scattering rate across the studied doping range. Their analysis supports a picture in which strong coupling between conduction electrons and commensurate low-energy antiferromagnetic spin fluctuations plays a central role in the normal state of LCCO.

The authors cite experimental evidence from neutron scattering and ARPES studies indicating that the hot spots are located at the intersections between the AFM zone boundary and the Fermi surface (FS). However, it is well established that the Fermi surface in cuprates evolves significantly with doping. As doping increases, changes in the FS topology and curvature will naturally shift the locations of these hot spots, which could in turn affect the doping dependence of the scattering rate. Furthermore, in the overdoped regime, the AFM weakens.

Was this evolution of the Fermi surface and weakening of the AFM explicitly incorporated into the modeling? If so, how sensitive are the results to the shifting hot-spot positions? If not, how might neglecting this effect influence the extracted anisotropic scattering rates and their doping dependence? Clarifying the extent to which FS evolution and AFM strength was considered—and assessing its quantitative impact—would help establish the robustness of the conclusions.

Overall, I find the conclusions reasonable and significant for the broader understanding of cuprate high- T_c superconductors.

Version 1:

Reviewer comments:

Reviewer #2

(Remarks to the Author)

This manuscript presents a comprehensive magnetotransport study of overdoped LCCO, combining high-field resistivity, magnetoresistance, and Boltzmann modelling. The authors identify a strongly anisotropic, mainly T -linear scattering channel that weakens with doping and tracks the suppression of T_c . Including CVCs, they attribute this scattering to commensurate antiferromagnetic spin fluctuations and link it to superconducting pairing. The RTA-based analysis is technically sound and supports a Fermi-liquid picture near antiferromagnetism, though some analytical points require clarification before final acceptance.

The authors have responded sincerely to all of the reviewers' comments in their reply and have proposed appropriate improvements and additional explanations. In accordance with the direction outlined in their reply, they have appropriately revised the resubmitted manuscript and have successfully improved the persuasiveness and the quality of the paper. For these reasons, I judge that the resubmitted manuscript is worthy of publication in Nature Physics.

The only point that caught my attention concerns the origin of the temperature-independent $1/\tau_{\text{SH}}(\phi)$ appearing in Eq. (1). However, even within spin-fluctuation theory, sublinear behavior of $1/\tau \propto \sqrt{T}$ is predicted near the hot spots (B. Stojković and D. Pines, PRB 55, 8576 (1996)), and this behavior is also reproduced within the FLEX approximation. Therefore, the existence of a sizable $1/\tau_{\text{SH}}(\phi)$ near the hot spots that persists down to low temperatures is not unnatural, but rather is an issue that awaits explanation based on future microscopic theories.

Reviewer #3

(Remarks to the Author)

The authors responded carefully and constructively to the reviewers' comments and made a number of revisions to improve the manuscript. They added clarifications to figures, captions, and text where the original presentation lacked sufficient explanation. Several sections were expanded to better describe the assumptions and physical interpretation of the transport model. Additional supplementary figures and analyses were included to demonstrate that the main results are not strongly dependent on specific fitting choices. In response to reviewer concerns, the authors discussed alternative interpretations of certain model components and acknowledged the remaining uncertainties, while providing reasonable justification for their approach. The response also clarified how doping-dependent changes in the Fermi surface were incorporated into the analysis. While some modeling assumptions remain simplified, the authors argue that these do not affect the main trends or conclusions. Overall, the revisions improve the clarity and transparency of the study and address most of the reviewers' concerns. I recommend this revised manuscript for publication.

Open Access This Peer Review File is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

In cases where reviewers are anonymous, credit should be given to 'Anonymous Referee' and the source.

The images or other third party material in this Peer Review File are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

Response to Reviewer comments:

List of changes to the manuscript in response to comments

#2.1 Figure 2: Figure caption: Sentence added to explain what the faint lines in panels h)-j) represent. The lines representing the mixed state resistivity in panels h)-j) have also been made fainter.

#2.2 Main manuscript: Page 7; Phrase '(strong scattering centres)' added to clarify the origin of $\tau_{HS}^{-1}(\varphi)$. Page 12: Sentence added describing the possibility that the residual hotspot is due to some form of non-local (k -dependent) impurity potential scattering.

#2.3 Supplementary Information: New Extended Data Figure 5 added, with accompanying text, to highlight the fact that the $\sin^{12}$ function used in the parameterisation of $\tau^{-1}(\varphi)$ is not unique but possesses the necessary features to enable the MR and Hall coefficient to be consistently captured. Reference to this new figure added on Page 9 of main manuscript.

#2.4 Main manuscript: Page 9: Extra sentence added to inform that we find that the most successful fits occur when the maxima of $\beta(\varphi)$ and $\tau_{HS}^{-1}(\varphi)$ coincide.

#2.5 Supplementary Information: Page 4: Change of variables and reformulation of SCTIF equation to include explicit role of magnetic field added below Eq. (2) and (3), together with new Eq. (4).

#2.6 Supplementary Information: CVC section: Sentence added to state that the modified velocities were included in the SCTIF Boltzmann calculations in the same way as the Zener-Jones estimation.

#2.7 Supplementary Information: Page 8: Extra paragraph added below Extended Data Table 2 demonstrating the consistency between the simulation parameters and the residual resistivity.

#3.1a Supplementary Information: Page 6: Sentence added in the second paragraph confirming that the location of the hotspots was specified for each x as the intersections of the underlying Fermi surface and the antiferromagnetic Brillouin zone.

#3.1b No changes were made to the manuscript in response to this comment.

Reviewer #2 (Remarks to the Author):

The authors extract the temperature-, field-, and doping-dependent scattering rate with high precision. On this basis, the authors establish a clear correlation between the strength of the T-linear scattering term, an effective spin-fluctuation coupling parameter, and the superconducting transition temperature T_c . They conclude that low-energy antiferromagnetic spin fluctuations act as the primary pairing glue in electron-doped cuprates. By contrasting the magnetotransport behaviour of electron- and hole-doped systems, the study suggests that the higher T_c in hole-doped cuprates cannot be explained solely by an enhancement of the same spin-fluctuation mechanism.

The analysis based on the relaxation-time approximation (RTA) is technically sound and carefully executed, and the overall conclusions are convincing. By incorporating CVCs, the authors present a unified framework that consistently accounts for the electrical resistivity, Hall coefficient, and magnetoresistance within a coherent picture. In this respect, the work provides strong support for a Fermi-liquid description in proximity to antiferromagnetism in electron-doped cuprates and represents a significant contribution to the field. While the main results are compelling, several aspects of the analysis would benefit from clarification in the revised manuscript.

We thank the Reviewer for their time and for their positive assessment of our study and the manuscript. The Reviewer raised some welcome and important comments regarding aspects of the analysis which we address below in the order in which they appeared in their report.

#2.1 In panels h, i, and j of Figure 2, the vertical axis shows $d\rho/dH$ and the horizontal axis shows H/T , with curves from 194 K (yellow) to 8 K (purple). Thinner lines are also present in these panels. The manuscript should state what these thinner lines represent and how they are to be interpreted.

The thin faint lines in panels h-j) represent those sections of the individual magnetoresistance (MR) curves that reside within the mixed state, not the normal state. Since the focus of this study is the normal state MR, we chose to de-emphasize the region of the derivatives corresponding to the mixed state so that the reader's eye is drawn to the key features of the data (the drop in the magnitude of the MR with decreasing temperature (T) and decreasing Ce content (x) and the crossover to a constant derivative at high field strengths (H) and low- T , corresponding to H -linear MR). We appreciate that we did not explain this aspect of the plots in our original submission so in the revised manuscript, we have added a sentence in the figure caption of Figure 2 to that effect. We have also modified panels h-j) to make the lines representing the mixed state resistivity fainter.

Figure 2: Figure caption: Sentence added to explain what the faint lines in panels h-j) represent. Panels h-j) also revised with the lines representing the mixed state resistivity made fainter.

#2.2 In Eq. (1), a specific functional form for $1/\tau_{\text{HS}}(\phi, T, x)$ is introduced. The physical origin of the T -independent $\tau_{\text{HS}}(\phi)$ term needs to be clarified. Does it represent non-local impurity potential scattering with angular dependence? In the revised manuscript, the functional form of $\tau_{\text{HS}}(\phi)$ is needed to be explained.

On page 7 of the main manuscript where we had originally introduced the scattering rate ansatz, we have now added '(strong scattering centres)' to clarify what $\tau_{\text{HS}}(\phi)$ represents, i.e.:

'To account for 3) – the H -linear MR – we also introduce a 'hotspot' (HS) term $\tau_{\text{HS}}^{-1}(\phi)$ that comprises a series of sharp peaks (strong scattering centres) whose locations depend on whether the dominant scattering is from spin or charge fluctuations. In the former case, the hotspots would be located where the AFM zone boundary connects the FS (red arrow in Fig. 3), consistent with earlier neutron scattering and photoemission studies showing that spin correlations in n -doped cuprates remain commensurate at $\mathbf{Q} = (\pi, \pi)$ within the SC doping range^{35,36} and corresponding hotspots at the intersection between the FS and the AFM zone boundary³⁷. For the latter, the hotspots link flat regions of FS near the (non-magnetic) zone boundary (horizontal grey line in Fig. 3)^{33,38-40}. Note that there are 8 hotspots in the former case, and only 4 in the latter.'

Later, in the first paragraph of page 12, we further discussed the possible physical origin of $\tau_{\text{HS}}^{-1}(\phi)$:

'The other outstanding issue is the persistence of H -linear MR to the lowest T (ref. 31). Within the model presented above, the H -linear MR is a result of impeded cyclotron motion due to the presence of hotspots. Of course, there may be a physical reason for this, e.g. the presence of a quantum critical phase and associated residual scattering off quantum fluctuations associated with the AFM order, but it is not immediately obvious why it should persist down to low- T . An alternative explanation is that this residual, small H -linear MR arises due to the compositional variation along the film created by the combinatorial synthesis itself. Longitudinal variation in the Hall voltage is a longstanding explanation for H -linear MR in metals⁴⁹ and indeed, has recently been proposed in the context of the cuprates⁵⁰.

We note, however, that H -linear MR is also observed at low T in LCCO films that are not grown combinatorially³¹.

Regarding the possibility that $\tau_{\text{HS}}^{-1}(\varphi)$ arises from some form of non-local (k -dependent) impurity potential scattering, we note that in Nd-LSCO, such strong k -dependence can arise from a strong variation in the density of states near the van Hove singularity (vHs) (Ref. [17] of the manuscript). We did not consider such a possibility here, since in LCCO the Fermi level lies far from the vHs and the Fermi velocity shows only modest k -dependence. Nevertheless, we cannot rule it out and in the revised manuscript we have added this possibility in the discussion on page 12.

Regarding the functional form of $\tau_{\text{HS}}^{-1}(\varphi)$, this was given in the Supplementary Information, page 8:

‘The hotspot scattering rate τ_{HS}^{-1} is constructed as a narrow Gaussian peak whose height and width are also given (in Extended Data Table 2). These HS peaks have a similar magnitude as the inelastic scattering rate, resulting in an overall Γ that is either peaked at the AFM zone boundary or at the antinodes, both scenarios providing the anisotropy that is required to reproduce the MR at low T .’

The actual form of $\tau_{\text{HS}}^{-1}(\varphi)$ arising from either spin or charge fluctuations is not presently known, but we believe that a Gaussian (or Lorentzian) peak is a natural assumption. We would like to stress, however, that the precise functional form of $\tau_{\text{HS}}^{-1}(\varphi)$ has a negligible influence on the fitting. Moreover, since it is taken to be a constant for all x , it has no bearing on the evolution of $g(x)$ across the doping series. Hence, while the inclusion of $\tau_{\text{HS}}^{-1}(\varphi)$ is required to capture the robustness of the H -linear MR and its preservation to low T , its functional form has no bearing on the main conclusions of the paper, namely the correlation between T_c and the coupling strength (deduced from the temperature and doping dependence of the MR) to spin fluctuations (deduced from the complementary analysis of the Hall response).

Main manuscript: Page 7; Phrase ‘(strong scattering centres)’ added to clarify the origin of $\tau_{\text{HS}}^{-1}(\varphi)$.
Page 12: Sentence added describing the possibility that the residual hotspot is due to some form of non-local (k -dependent) impurity potential scattering.

#2.3 In Eq. (1), $\sin^{12}(2\varphi)$ is taken, in the spin-fluctuation scenario, to be proportional to $\sin^{12}(2\varphi \pm \dots)$. The origin of the exponent 12 is not explained. The authors should justify this choice.

The higher the exponent n in a $\sin^n(2\varphi)$ parameterisation, the more sharply peaked the maxima in φ . The choice of $n = 12$ for the spin-fluctuation scenario was made for two reasons: (i) it produces well-defined hotspots at the AFM zone boundary, with clear minima between adjacent hotspots, and (ii) its form is such that the minima in $\tau^{-1}(\varphi)$ at the nodes (which are closer to the hotspots) are higher than those the antinodes. This second aspect is crucial in the discussion of the Hall response, since it is precisely this disparity between the nodes and anti-nodes that enables the T - (and x -) dependence of the Hall coefficient to be captured with the same ansatz (once current vertex corrections are also taken into account).

Saying that, however, any function that satisfies these two criteria would have the same effect on the MR. To demonstrate that it is the overall form of the scattering rate that is important, Fig. R1 compares simulations for 20 K and 50 K (the full temperature range of our fitting) performed using the $\sin^{12}$ function (as presented in the main article) and a Gaussian function of similar width and height. In both cases the overall magnitude and form of the MR is the same, with slight differences between the two forms of the scattering rate responsible for minor discrepancies.

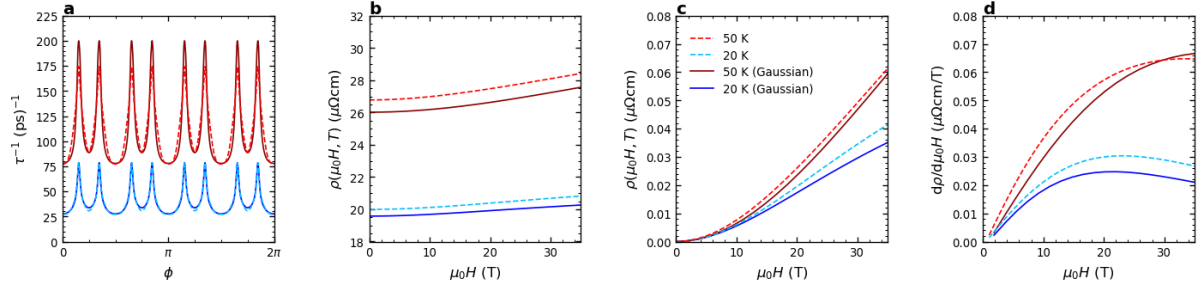


Fig. R1) Sinusoidal vs. Gaussian functional form of the scattering rate. (a) The scattering rate at 20 K (blue) and 50 K (red) using the $\sin^{12}(F(\phi))$ form from the manuscript (dashed lines) and a Gaussian form (solid lines). Note that the 50 K scattering rate has been offset by 50 ps^{-1} for clarity. (b) The corresponding MR simulation in absolute values, (c) normalised to $\rho(0)$, and (d) its derivative, clearly showing comparable behaviour between the two. Small differences between the two can be attributed to slight differences in the scattering rate.

Note that changing the width of the anisotropic component (i.e. increasing the width of the Gaussian, or reducing the power of the sin function) will have an impact on the resulting simulations, as it is the anisotropy of the scattering rate that controls the magnitude and linearity of the MR itself.

In response to the Reviewer's comment, we have now added this figure to the Supplementary Information, along with some accompanying text. A reference to this figure has also been added to the main manuscript (page 9).

Supplementary Information: New Extended Data Figure 5 added, with accompanying text, to highlight the fact that the $\sin^{12}$ function used in the parameterisation of $\tau^{-1}(\phi)$ is not unique but possesses the necessary features to enable the MR and Hall coefficient to be consistently captured.

#2.4 The relationship between $\beta(\phi)$ and $\tau_{\text{HS}}^{-1}(\phi)$ should be clarified. If a common hotspot width is assumed for both terms, the physical justification for this assumption needs to be stated.

As described in the main article, each element of $\tau^{-1}(\phi, T, x)$ captures specific, yet key aspects of the magnetotransport data in LCCO; $\beta(\phi)$ defines the anisotropy of the inelastic scattering rate(s) that generate(s) the T -dependence of $\rho_{ab}(T)$, the growth in the MR with temperature and its crossover to H -linearity at intermediate field strengths, and crucially, together with the incorporation of current vertex corrections, the T -dependence of $R_{\text{H}}(T)$. $\tau_{\text{HS}}^{-1}(\phi)$, on the other hand, is included in order to account for the robustness of the H -linear MR to high field strengths and low temperature.

During the fitting process, we tried to decouple the loci of the peaks in $\beta(\phi)$ and $\tau_{\text{HS}}^{-1}(\phi)$, but none of those simulations captured the entire phenomenology well (see, e.g. row c of Extended Data Fig. 4). Hence, in the end, the data compelled us to combine them together. This also make obvious physical sense too. In the final parameterisation, the width and height of $\tau_{\text{HS}}^{-1}(\phi)$ were chosen to match, within reason, the shape of $\beta(\phi)$ (albeit with the caveat that while the magnitude of the component incorporating $\beta(\phi)$ evolved with temperature and doping, the size and form of $\tau_{\text{HS}}^{-1}(\phi)$ did not). As example of the combined scattering rate is shown in Fig. R2.

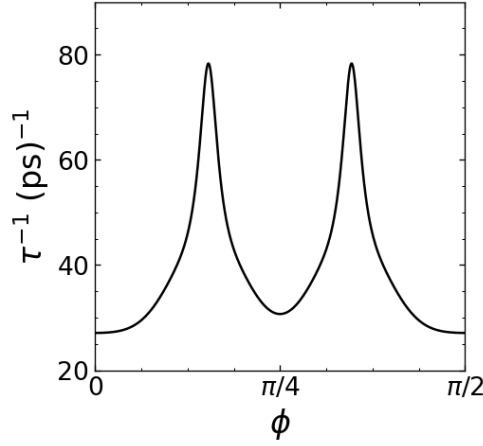


Fig. R2 Blow-up of the scattering rate, incorporating both of the anisotropic components $\beta(\varphi)$ and $\tau_{\text{HS}}^{-1}(\varphi)$ for $x = 0.159$ at $T = 20$ K.

Since we had originally explained in the main article that, ‘the parameterisations of $\tau_{\text{HS}}^{-1}(\varphi)$ and $\beta(\varphi)$ are somewhat arbitrary and as extensive analysis revealed, have only a modest influence on the quality of the fitting (other than to set the departure from H -linear MR)’, we did not think it was necessary to add any further remarks on this aspect of the parameterisation other than to mention that the fitting procedure indicated that the loci of the maxima in $\beta(\varphi)$ and $\tau_{\text{HS}}^{-1}(\varphi)$ coincided.

Page 9: Extra sentence added to inform that we find that the most successful fits occur when the maxima of $\beta(\varphi)$ and $\tau_{\text{HS}}^{-1}(\varphi)$ coincide.

#2.5 The SCTIF formalism is introduced in Eqs. (2) and (3) of the Supplementary Information, but key elements, including the explicit role of the magnetic field, are omitted. Since this formalism underpins the quantitative analysis, the full set of equations actually used in the calculations should be presented.

The applied magnetic field is implicit within the SCTIF and only enters through cyclotron orbital motion of the quasiparticles. We make the role of the magnetic field explicit via a change of variables from t to φ , the (azimuthal) angle swept around the Fermi surface under the influence of the field $\mathbf{H}/c$.

Writing $\varphi = \omega_c t$, where the cyclotron frequency: $\omega_c(\varphi) = eB \frac{\vec{k}_F(\varphi) \cdot \vec{v}_F(\varphi)}{\hbar k_F^2(\varphi)}$

we can re-express the SCTIF formalism as:

$$\sigma_{ij} = \frac{1}{4\pi^3} \int_{FS} d^2 k \frac{1}{\hbar v_F} q v_i \int_0^{2\pi} d\varphi \frac{q v_j(\varphi)}{\omega_c(\varphi)} \int_0^\infty d\varphi' \exp\left(\int_\varphi^{\varphi'} d\varphi'' \frac{-\varphi''}{\omega_c(\varphi'') \tau(\varphi'')}\right)$$

In response to the Reviewer’s comment, we have now included this additional expression (as Eq. (4)) in the Supplementary Information.

Supplementary Information: Page 4: Change of variables and reformulation of SCTIF equation to include explicit role of magnetic field added below Eq. (2) and (3), together with new Eq. (4).

#2.6 Extended Data Figure 9 compares magnetoresistance calculated with and without current-vertex corrections (CVCs), but the procedure used to compute the CVC-included magnetoresistance

is not described in sufficient detail. Please explain how CVCs are incorporated within the SCTIF framework.

CVCs are included in the simulations through a modification of the velocities v_x and v_y as is described in Eq. 11 through 13 of the Extended Data. We use the form:

$$v_n^*(\varphi) = \frac{1}{1 - \epsilon_k^2} (v_n(\varphi) + \epsilon(\varphi)v_n(\varphi'))$$

Where $n = x, y$ and $\varphi' = \varphi - (\pi, \pi)$. We ignore the prefactor as it requires knowledge of the antiferromagnetic correlation length, which we do not have, and define

$$\epsilon(\varphi) = \exp \frac{-(\varphi - \varphi_n)^2}{2\sigma}$$

with $\sigma = 0.06$ as the width of a Gaussian centred at the hotspot angle.

To clarify this procedure in the manuscript, we have added a sentence in the Supplementary Information explicitly stating that the same procedure used in the Zener-Jones analysis was employed in the SCTIF formalism.

Supplementary Information: CVC section: Sentence added to state that the modified velocities were included in the SCTIF Boltzmann calculations in the same way as the Zener-Jones estimation.

#2.7 The manuscript should clarify whether the value of τ_{imp} used in Eq. (1) is quantitatively consistent with the experimentally measured residual resistivity shown in Extended Data Figure 1. Demonstrating this consistency would strengthen the internal coherence of the analysis.

Since τ_{HS}^{-1} is sharply peaked around the intersections of the Fermi surface and the AFM Brillouin zone, the dominant contribution to the residual resistivity, by far, is τ_{imp}^{-1} . Indeed, ignoring τ_{HS}^{-1} and the slight in-plane anisotropy in k_F and v_F , we can write the expression for ρ_0 as;

$$\rho_0 = \frac{2\pi\hbar c}{e^2 k_F v_F} \frac{1}{\tau_{\text{imp}}}$$

Inserting the values for k_F ($= 5.8 \times 10^9 \text{ m}^{-1}$) and v_F ($= 5.0 \times 10^5 \text{ ms}^{-1}$) from Fig. 4a1 of the main article and for τ_{imp}^{-1} ($= 27 \text{ ps}^{-1}$) from Extended Data Table 2 of the Supplementary Information, we arrive at $\rho_0 \approx 15 \mu\Omega\text{cm}$. Using the hotspot parameters quoted in Extended Data Table 2, we estimate that the angle-averaged $\tau_{\text{HS}}^{-1} \approx 4 \text{ ps}^{-1}$, giving a total $\rho_0 \approx 17.2 \mu\Omega\text{cm}$. From Extended Data Figure 1, we estimate that the actual value of $\rho_0 \approx 17.5 \mu\Omega\text{cm}$. Hence, our parameterisation is indeed consistent with the residual resistivity.

To demonstrate this consistency, we have added an extra paragraph below Extended Data Table 2 summarising this considerations.

Supplementary Information: Page 8: Extra paragraph added below Extended Data Table 2 demonstrating the consistency between the simulation parameters and the residual resistivity.

Reviewer #3:

A detailed and systematic investigation of the temperature dependence of resistivity (and magnetoresistivity) over a broad doping range is essential. In this paper, the authors report such a study in the electron-doped cuprate LCCO, using fine doping steps across the entire overdoped region of the phase diagram. The samples are of exceptionally high quality. While the overall resistive

and superconducting properties of this sample series were reported previously (Ref. 10), the present work provides a much more in-depth and comprehensive analysis.

One key new insight comes from a semiclassical Boltzmann treatment that incorporates strong anisotropy in the inelastic scattering channel associated with the so-called “hot spots.” Furthermore, through modeling of the Hall conductivity, the authors identify the location of these hot spots along the antiferromagnetic Brillouin zone boundary. This enables them to quantify the temperature-dependent anisotropic scattering rate across the studied doping range. Their analysis supports a picture in which strong coupling between conduction electrons and commensurate low-energy antiferromagnetic spin fluctuations plays a central role in the normal state of LCCO.

Overall, I find the conclusions reasonable and significant for the broader understanding of cuprate high- T_c superconductors.

We thank the reviewer for their time and for their positive assessment of our study and the manuscript. The reviewer raised one query regarding the evolution of the hotspots – their location and strength – and its influence on the fitting that we address below.

#3.1 The authors cite experimental evidence from neutron scattering and ARPES studies indicating that the hot spots are located at the intersections between the AFM zone boundary and the Fermi surface (FS). However, it is well established that the Fermi surface in cuprates evolves significantly with doping. As doping increases, changes in the FS topology and curvature will naturally shift the locations of these hot spots, which could in turn affect the doping dependence of the scattering rate. Furthermore, in the overdoped regime, the AFM weakens. Was this evolution of the Fermi surface and weakening of the AFM explicitly incorporated into the modeling? If so, how sensitive are the results to the shifting hot-spot positions? If not, how might neglecting this effect influence the extracted anisotropic scattering rates and their doping dependence? Clarifying the extent to which FS evolution and AFM strength was considered—and assessing its quantitative impact—would help establish the robustness of the conclusions.

Regarding the first point, we did indeed include the shift of the loci of the hotspots as a function of doping. HS location with doping incorporated into model. In the last line of the first paragraph on page 8 of the main article, the position of the HS for $x = 0.159$ is stated within the expression for $\beta(\varphi)$. For all other x values, the position shifted according to the evolution of the Fermi surface. We acknowledge that this was not stated explicitly in the original manuscript and so in the revised manuscript, a sentence has been added to this effect.

#3.1a Supplementary Information: Page 6: Sentence added in the second paragraph confirming that the location of the hotspots was specified for each x as the intersections of the underlying Fermi surface and the antiferromagnetic Brillouin zone.

Regarding the second point (the softening of the AFM with doping), we did not include this as we wanted to minimise the number of parameters in the fits. As stated in the paragraph spanning pages 8 and 9 of the Supplementary Information:

“As x increases, it is expected that the hotspots broaden or diminish in size, in tandem with $g(x)$, as one might expect upon approaching the FL regime. Indeed, we find that increasing the width of the hotspot by a factor of two or decreasing the size of the hotspot by a factor of 5 reduces the resistivity by $1 \mu\Omega\text{cm}$. This behaviour may explain the larger increase of $g(x)$ in our simulations below $x = 0.14$ and at lower T : the sharpening and strengthening of hotspots would contribute to the increase in the resistivity in parallel with the anisotropic T -linear term. Note that the strength of the hotspot can only

be quantified experimentally if breakdown in the form of MR saturation is observed. Thus, for the sake of transparency and simplicity, we keep the height of τ_{HS}^{-1} constant at all x and T .”

Including the evolution of this softening would modify the absolute value of $g(x)$ (our only variable fitting parameter) but not the overall trend. It would also require very detailed knowledge of the spin fluctuations at each doping and temperature which is currently lacking in LCCO. To minimise the number of variable parameters, we thus chose to keep the height of τ_{HS}^{-1} constant at all x and T .

#3.1b No changes were made to the manuscript in response to this comment.

Dear Dr. Abergel, Dear David,

Thank you for sending over the final Reviewers' comments and for inviting us to resubmit a suitably revised and formatted manuscript to *Nature Physics*. Reviewer #3 had no additional queries to address, while Reviewer #2 had only one new query, which we address here, together with a description of the corresponding change we have made to the manuscript. As instructed in the Author Checklist, we have also fully reformatted the manuscript to be compliant with editorial guidelines.

List of changes to the manuscript in response to comments

#2.1 Methods: Final paragraph of penultimate section: Sentences added (highlighted in blue) to that paragraph stating the possible persistence of hotspots down to low temperatures arising from spin fluctuation theory.

'The other outstanding issue is the persistence of H-linear MR to the lowest T (ref. 31). Within the model presented above, the H-linear MR is a result of impeded cyclotron motion due to the presence of hotspots. Of course, there may be a physical reason for this, e.g. non-local (k -dependent) impurity potential scattering or the presence of a quantum critical phase and associated residual scattering off quantum fluctuations associated with the AFM order, but for the latter, it is not immediately obvious why it should persist down to low- T . An alternative explanation is that this residual, small H-linear MR arises due to the composition variation along the film created by the combinatorial synthesis itself. Longitudinal variation in the Hall voltage is a longstanding explanation for H-linear MR in metals⁶⁸ and indeed, has recently been proposed in the context of the cuprates⁶⁹. We note, however, that H-linear MR is also observed at low T in LCCO films that are not grown combinatorially³¹. **With this in mind, it is tempting to attribute the persistence of a sizable $1/\tau_{\text{HS}}$ down to low temperatures to the sublinear behaviour of $1/\tau \propto \sqrt{T}$ predicted near the hot spots⁷⁰ within spin-fluctuation theory, though this is clearly an outstanding issue that awaits explanation based on future microscopic theories.'**

A reference to the article by Stojkovic and Pines also added (Ref. 70).

A small number of typos and grammatical errors were also corrected (not listed). Please note that none of the main conclusions have been modified as a result of the above changes.

We trust that you find everything in order and we look forward in due course to receiving the final proofs.

Yours truly,

Nigel Hussey & Caitlin Duffy (on behalf of all co-authors)

Reviewer comments:

Reviewer #2:

This manuscript presents a comprehensive magnetotransport study of overdoped LCCO, combining high-field resistivity, magnetoresistance, and Boltzmann modelling. The authors identify a strongly anisotropic, mainly T-linear scattering channel that weakens with doping and tracks the suppression of T_c . Including CVCs, they attribute this scattering to commensurate antiferromagnetic spin fluctuations and link it to superconducting pairing. The RTA-based analysis is technically sound and supports a Fermi-liquid picture near antiferromagnetism, though some analytical points require clarification before final acceptance.

The authors have responded sincerely to all of the reviewers' comments in their reply and have proposed appropriate improvements and additional explanations. In accordance with the direction outlined in their reply, they have appropriately revised the resubmitted manuscript and have successfully improved the persuasiveness and the quality of the paper. For these reasons, I judge that the resubmitted manuscript is worthy of publication in *Nature Physics*.

We thank the Reviewer for their time and for recommending the revised manuscript for publication in *Nature Physics*. The Reviewer did raise one additional query that we address below.

#2.1 The only point that caught my attention concerns the origin of the temperature-independent $1/\tau_{\text{SH}}(\phi)$ appearing in Eq. (1). However, even within spin-fluctuation theory, sublinear behavior of $1/\tau \propto \sqrt{T}$ is predicted near the hot spots (B. Stojković and D. Pines, PRB 55, 8576 (1996)), and this behavior is also reproduced within the FLEX approximation. Therefore, the existence of a sizable $1/\tau_{\text{SH}}(\phi)$ near the hot spots that persists down to low temperatures is not unnatural, but rather is an issue that awaits explanation based on future microscopic theories.

We thank the Reviewer for alerting us to this possibility and in the revised manuscript, we have added a reference to the article by Stojkovic and Pines along with a couple of sentences summarising this point.

Methods: Final paragraph of penultimate section: Sentences added to that paragraph stating the possible persistence of hotspots down to low temperatures arising from spin fluctuation theory. A reference to the article by Stojkovic and Pines also added (Ref. 70).

Reviewer #3:

The authors responded carefully and constructively to the reviewers' comments and made a number of revisions to improve the manuscript. They added clarifications to figures, captions, and text where the original presentation lacked sufficient explanation. Several sections were expanded to better describe the assumptions and physical interpretation of the transport model. Additional supplementary figures and analyses were included to demonstrate that the main results are not strongly dependent on specific fitting choices. In response to reviewer concerns, the authors discussed alternative interpretations of certain model components and acknowledged the remaining uncertainties, while providing reasonable justification for their approach. The response also clarified how doping-dependent changes in the Fermi surface were incorporated into the analysis. While some modeling assumptions remain simplified, the authors argue that these do not affect the main trends or conclusions. Overall, the revisions improve the clarity and transparency of the study and address most of the reviewers' concerns. I recommend this revised manuscript for publication.

We thank the Reviewer for their time and for their positive assessment of our study and for recommending its publication in *Nature Physics*.