

Chiral-nematic Fermi liquid state as the parent state of kagome metals and superconductors

Corresponding Author: Professor Hong-Jun Gao

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

This manuscript addresses the long-standing open question regarding the origin of the chiral charge density wave (CDW) order, the so-called "parent" state in kagome metals and superconductors, which represents a central unresolved issue in low-temperature kagome physics. Using spectroscopic-imaging scanning tunneling microscopy (SI-STM), the authors investigate Ti-doped CsV₃Sb₅ with suppressed CDW order and report the discovery of a parent chiral-nematic Fermi liquid state, supported by a set of key experimental observations. Overall, this work fills a critical knowledge gap in quantum materials research and is highly suitable for publication in Nature Communications. Nevertheless, several points require further clarification and refinement to strengthen the scientific rigor and persuasiveness of the main conclusions.

The evolution of superconductivity relative to the proposed parent state needs explicit discussion. While the manuscript centers on the "parent" state in kagome metals and superconductors, its connection to superconductivity remains largely unaddressed. As shown in Fig. S9, a full U-shaped gap feature is observed. The authors should clarify the evolution of the superconducting gap across different Ti doping levels, specifically for $x=0, 0.05, 0.15, 0.27$. A direct, systematic comparison of superconducting behavior as a function of Ti concentration must be elaborated in detail.

I recommend that the authors directly compare the evolution of quasiparticle interference (QPI) spectra across different Ti doping levels in a main-text figure. This would greatly assist readers in tracking the evolution of chiral-nematic order and reinforce the key experimental narrative.

Structural characterization data for different Ti doping concentrations should be provided. For instance, the authors should specify the type and density of doping-induced defects, along with supporting evidence such as XRD measurements of lattice parameter variations or TEM characterizations. Additionally, it is necessary to clarify whether this "parent phase" manifests distinct experimental signatures in the resistance–temperature curves of Ti-doped CsV₃Sb₅ samples.

The authors mention the observation of "residual chiral-nematic QPI features" in samples with chiral CDW order, which they use to argue that CDW-induced exotic states derive from the chiral-nematic Fermi liquid. To solidify the causal relationship between the parent state and CDW-stabilized phases, the authors should briefly clarify how these residual QPI signatures differ from those in the parent state, for example, in terms of spectral intensity, spatial distribution, or energy dependence. Although the work presents novel findings, it could better contextualize this study within existing literature on nematic Fermi liquids and chiral symmetry breaking in kagome materials. For instance, explicitly distinguishing this chiral-nematic Fermi liquid state from previously reported nematic phases (e.g., rotational symmetry breaking versus mirror symmetry breaking) would more effectively highlight the conceptual novelty and advance of this discovery.

Reviewer #2

(Remarks to the Author)

The paper by Z. Huang et al., presents interesting scanning tunneling microscopy results on the Kagome metal system CsV_{3-x}Ti_xSb₅. In particular, the present detailed quasi-particle interference (QPI) spectra for different levels of Ti doping, including $x = 0.15$, where the CDW is suppressed. They find that the peaks in QPI maps, which are linked to scattering vectors spanning constant energy contours, exhibit features consistent with a nematic chiral-symmetry breaking the normal metallic phase, which they argue is the true "parent" phase from which chiral CDW and superconducting orders emerge. The results are compared with simulations based on a simplified joint density-of-states model with a band structure derived from ab initio simulations. The authors' results, if correct, suggest that the system exhibits a degree of rotational and mirror-symmetry breaking at all Ti-doping levels. This finding could be used to constrain models for the chiral CDW order in

these materials.

Overall, I found the work to be very interesting, and the paper is well written. The subject matter is also very timely, considering the community's strong interest in Kagome metals. For these reasons, I am inclined to view the paper as appropriate for Nature Communications if the authors can satisfactorily address the comments and questions provided. I, therefore, suggest that the authors be given a chance to revise and resubmit this work for further consideration.

1. The authors use the peak locations of several QPI vectors as evidence for the symmetry breaking. However, they also state that they align the Bragg peaks in the spectra after 60 and 120 degree rotations. Does this mean that the Bragg peaks (and therefore underlying lattice structure) also don't follow the expected lattice symmetries? Can they please clarify this matter?
2. The comparison to the theory simulations needs further justification and discussion. The authors are essentially comparing the QPI patterns against a JDOS calculation and the ab initio band structure at a fixed $K_z = \pi$. No justification for this value is given, and there is no reason to expect that electrons tunnel into the system at a fixed k_z value. Note that the theory for tunneling into a 3D band structure has been worked out [see Rhodes et al., PRB 107, 045107 (2023)]. Why not perform calculations for the full band structure? Why is K_z the right momentum here? How robust are the conclusions to different values K_z ?
3. Related to the above point, I would like the authors to assess the role of the impurities themselves more thoroughly. Why is it okay to ignore the scattering potential? How do the authors know that the impurities are causing some of the symmetry breaking they are observing in the QPI? Some analysis of the real-space density modulations near the impurities, along with a discussion of the dominant impurities and how they affect the structure, might help address this issue.
4. Supplementary Figure 2 shows how the QPI peaks are fit; however, it is very difficult to read, and I am unable to gauge the quality of the fits. I think the authors should revisit this scale and expand the y-axis so the peak and the quality of the fit can be more readily judged.
5. The mass enhancement values extracted from the QPI measurements appear inconsistent with the e-ph coupling values reported in Ref. 32, and this discrepancy needs to be addressed. For example, the authors claim they see features in the QPI consistent with a phonon kink but extract a mass enhancement that is less than the value of $1 + \lambda$ inferred in Ref. 32. Can the authors reconcile these differences? Note that QPI measurements that have previously resolved the kinks in simple systems extract comparable mass enhancements, so this discrepancy needs to be addressed.

Reviewer #3

(Remarks to the Author)

Referee Report – “The ‘parent’ state in kagome metals and superconductors: Chiral-nematic Fermi liquid state”

The study of correlated and topological phases in kagome metals has attracted substantial attention in condensed matter physics, both experimentally and theoretically. In this context, the work by Huang et al. is timely and potentially significant. The proposal of a chiral-nematic Fermi liquid as a parent state is particularly interesting, as it suggests a hierarchical mechanism leading to chiral superconductivity, rather than a scenario governed by multiple competing orders.

Experimentally, the authors employ scanning tunneling microscopy and spectroscopy, including quasiparticle interference (QPI) measurements, on Ti-doped $\text{CsV}_3\text{-xTi}_x\text{Sb}_5$. For $x = 0.15$, no charge density wave (CDW) order is observed, and Fourier-transformed QPI patterns indicate broken mirror symmetries. The comparison between different surface regions suggests the presence of at least two chiral domains. Furthermore, tunneling spectra at 0.4 K exhibit a U-shaped superconducting gap in the spatially averaged local density of states. For $x = 0.05$, similar symmetry reduction is observed alongside diffraction signatures of CDW order.

The experimental effort is substantial and commendable. The systematic characterization across doping levels and temperatures is necessary to support the central claim that a chiral-nematic Fermi liquid underlies both the CDW and superconducting phases.

However, in its current form, the manuscript requires significant clarification and additional analysis before it can be considered for publication.

Major Comments

Surface preparation and its impact on electronic structure

The authors state that Cs atoms are removed by the STM tip to obtain a clean Sb surface. While this may facilitate QPI measurements, it raises a critical concern: how does the removal of Cs atoms—present in the bulk—affect the surface electronic structure and symmetry? Could this procedure itself induce symmetry breaking or modify the observed QPI patterns? This issue must be addressed quantitatively or, at minimum, discussed in detail.

Crystal symmetry and notation

The symmetry description is ambiguous. The space group $P6/mmm$ (line 78) implies C_6 symmetry, whereas later (line 103)

the symmetry is described as “C3 plus inversion.” Are these statements referring to bulk versus surface symmetry? Do the C3 axis and inversion center coincide spatially? The precise symmetry group relevant for the QPI analysis should be clearly stated.

Reliability of QPI intensity analysis (Fig. 1d–g, 1e, 1g)

Comparing Fig. 1e and 1g, electronic-structure-related features appear with inverted intensity (e.g., A–H1 high in g but low in e). How are set-point effects and topographic contributions removed in the Fourier-transformed dI/dV data? Is the observed asymmetry intrinsic or an artifact of measurement conditions? This requires explicit clarification.

Affine transformation and Bragg peak alignment (Fig. 1e, 1g)

An affine transformation (presumably a Lawler–Fujita correction) is applied to align Bragg spots. The exact procedure should be specified. How are genuine lattice distortions or physical inequivalence of Bragg vectors excluded? How is the remaining intensity difference between corrected Bragg peaks explained?

Relation between Fig. 1g and Fig. 2

It is unclear whether Fig. 2 is derived from the same dataset as Fig. 1g. If so, this should be explicitly stated; if not, differences in acquisition conditions should be clarified.

Signal-to-noise and robustness of symmetry breaking (Fig. 2b–d, 2g)

Since Fig. 2 illustrates the central experimental claim, a quantitative estimate of the signal-to-noise level is required. In panel 2g, an additional ring-like feature slightly shorter than q1 appears in the central region—this should be addressed (artifact vs. physical signal). Are the line profiles shown in panels 2c and 2d raw data or averaged? If averaging is performed, the procedure should be specified. Furthermore, why is the analysis consistently shown at ~10 mV (or 5 mV in the SI)? Is the observed symmetry breaking strongly bias-dependent? In panel 2b, the use of grey dashed lines is confusing and should be clarified.

QPI fitting procedure and dispersion analysis (Fig. 3c, 3d, Fig. S2)

The fitting methodology lacks transparency. What are the “Gaussian-like backgrounds” that are subtracted, and why do they vary with bias voltage? The Lorentzian fits shown in Fig. S2 appear ambiguous; quantitative measures of fit quality should be provided. Are the line profiles averaged in momentum space? In panels 3c and 3d, linear dispersions are fitted to extract Fermi velocities. The comparison with DFT (lines 185–194) highlights directional dependence in experiment that is absent in theory—how would this comparison change when including the proposed Pomeranchuk distortion (line 142)? Deviations from linear dispersion are attributed to electron–phonon coupling: which phonon mode is responsible, and is there a corresponding suppression in QPI intensity?

Consistency between $x = 0.15$ and $x = 0.05$ (Fig. 4e)

In Fig. 4, the identification of q1, q2, and q3 becomes difficult. In the line cut shown in panel 4e (is this averaged?), q3 falls below the noise level in two out of three curves, q1 shows little variation, and the shift of q2 differs noticeably from Fig. 2c. Given these discrepancies, in what sense do both doping levels exhibit the same chiral-nematic Fermi surface?

Bogoliubov QPI analysis

In lines 291–293, the authors discuss QPI of Bogoliubov quasiparticles. To mitigate experimental artifacts due to set-point and spatial modulation effects, such data are often analyzed using $z(r, E) = g(r, +E)/g(r, -E)$ or equivalent symmetrization procedures. Have the authors performed such an analysis? If so, are the symmetry-breaking features robust?

Recommendation

The manuscript addresses an important and timely problem and presents extensive experimental work. However, the central claim—the identification of a chiral-nematic Fermi liquid as a parent state—relies on subtle symmetry analysis that is not yet sufficiently supported.

I therefore recommend a major revision. The issues outlined above, particularly those concerning data processing, symmetry interpretation, and robustness of the QPI analysis, must be addressed before the conclusions can be considered convincing.

Version 1:

Reviewer comments:

Reviewer #2

(Remarks to the Author)

I have read the author’s reply to my comments and their revised manuscript. The authors have addressed comments 1 and 4 of my initial report. However, I find their responses to points 2 (the choice of K_z), 3 (the role of impurities), or 5 (the mass discrepancies) less persuasive. I will provide some comments below on why I am not persuaded. But I first want to emphasize that these points are not necessarily reasons not to publish the work (which I view as being more experimentally focused) provided the authors provide frank discussions of these points and how they might affect the conclusions.

Choice of K_z : The authors essentially argue that, experimentally, the system is two-dimensional, and the ARPES data agree with the dispersion at $k_z = \pi$. This is not a justification for taking the $k_z = \pi$ value from the ab initio calculations. This kind of

discrepancy occurs frequently in QPI modeling, particularly in correlated materials, where DFT tends to overestimate screening. One approach is to use an empirical fit to ARPES data to model the QPI data. In essence, this is what the authors are doing by cherry-picking the k_z value that best agrees with their data. If they wish to do this rather than model the entire k_z dispersion, then they should state it clearly in the text so readers are alerted to the approximations and assumptions being used. As the paper is written, it implies stronger agreement between DFT and the experiments, when, in fact, they are ad hoc, selecting one k_z value.

Impurities: The author's response cites early QPI theory, in which the full intensity is approximated by a factorized expression. This expression is a weak-coupling approximation, where the JDOS provides a better approximation to the QPI, but several theoretical works since then have shown that impurity effects can be important, particularly for strong scatterers. I believe the paper would be strengthened considerably by treating a proper T-matrix calculation, even for a point defect on one of the sublattices. I understand that the authors might like to keep the theory simple, but these calculations are not that hard for point-like defects.

The discrepancies in the mass: In their reply, the authors emphasize that they are focused on the low-energy dispersion, while the kink analysis of the ARPES bands is more focused on renormalizations at higher energy scales. I disagree with this assertion. In an analysis of kink structures, as in Ref. 32, one extracts the value of λ from the data. The mass enhancement at the Fermi level is related to λ as $m^*/m = (1 + \lambda)$ and should be directly related to the enhancement discussed by the authors. For this reason, I don't believe this discrepancy is due to different energy ranges examined by the two experiments, and their explanation in the revised paper is incorrect. While I agree with the authors that this is not the main point of the paper, it is more than fair to ask them to explain why they think the results don't agree if they are going to compare the mass enhancements obtained in the two experiments.

Reviewer #3

(Remarks to the Author)

In my previous review, I recommended major revision because the central claim, the identification of a chiral-nematic Fermi liquid as a parent state, relied on subtle symmetry analysis that I felt was not yet sufficiently supported.

The authors have now addressed my concerns in a thorough and constructive manner, in particular through new control measurements, Feenstra-normalized reanalysis, checks on lattice/Bragg-vector effects, and expanded analysis across samples and dopings. Together, these additions make a convincing case that the reported rotational and mirror-symmetry breaking is a genuine observation, rather than an artefact of the intricate experimental and data-processing details involved in QPI analysis.

The broader interpretation as a chiral-nematic Fermi-liquid parent state remains, in my view, plausible and well motivated rather than uniquely proven. Further work may clarify its microscopic origin and relation to competing ordered phases, which only adds to the significance of the present results. I am therefore happy to recommend publication.

This does not affect my recommendation, but I would encourage the authors to strengthen the Data Availability statement. Given the nuanced nature of QPI analysis, access to both raw and processed data would substantially improve reproducibility and independent verification of the central claims. Where feasible, these data should be deposited in an appropriate public repository.

Version 2:

Reviewer comments:

Reviewer #2

(Remarks to the Author)

I am satisfied with the author's reply to my second report and with their revisions. I believe these changes have strengthened both the presentation and robustness of the results and I am happy to recommend publication at this time.

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Responses to the reviewers' comments

We thank the Reviewers for their thoughtful evaluation and positive assessment of our work. Their constructive comments have helped to further strengthen the manuscript. Reviewer #1 highlighted that our study addresses the long-standing question of the origin of the chiral CDW and “fills a critical knowledge gap,” while Reviewer #2 described the work as “very interesting,” “well written,” and “very timely.” Reviewer #3 considered the results “timely” and “potentially significant,” and noted that the identification of the parent chiral-nematic Fermi liquid is “particularly interesting,” with “substantial and commendable” experimental effort.

We have carefully addressed all comments and revised the manuscript accordingly. We believe these revisions have improved the clarity and impact of the work, and we hope that our responses satisfactorily address the Reviewers' concerns.

Summary of major changes to the manuscript:

- We added new Fig. S11 and discussion of evolution of superconductivity as Section A in the Supplementary Information, and discuss them in the manuscript main text.
- We added new Fig. 4g to help in tracking the evolution of QPI across different Ti doping level and discuss them in the manuscript main text.
- We added discussions about structural and transport data in the revised manuscript.
- We added discussions about the differences and similarities between residual QPI patterns in $x=0.05$ sample and QPI patterns in $x=0.15$ sample.
- We added discussions to highlight the difference between our chiral-nematic Fermi liquid and previously reported chiral and nematic phases.
- We added new Fig. S12 and discussion of affine transform and lattice structure symmetry analysis as Section B in the Supplementary Information.
- We added discussion to better justify the choice of $k_z = \pi$ Fermi surface when comparing with theory in the Methods.
- We added a new Supplementary Information Section C and new Fig. S13 to clarify the role of impurities.
- We added a new Supplementary Information Section D to detail the data fitting procedure and revised the scale of Fig. S2.
- We have clarified in the revised manuscript to distinguish electron-phonon coupling strength and extracted renormalized mass.
- We added a new Supplementary Information Section E and Fig. S14 to discuss the rotational- and mirror-symmetry-breaking QPI of Cs surface. We also cited Fig. S14 in the main text.
- We revised “ C_3 plus inversion” to make it clearer.
- We updated the Feenstra-normalized conductance map in Fig. 3 and the extracted values in the revised manuscript. We added new Fig. S15 and a discussion on the removal of set-point effects in Methods.
- We discussed the signal-to-noise and low-frequency signals in a new Supplementary Information Section F.
- We added a new Fig. S16 to show the chiral QPI on a $x=0.04$ sample.
- We added a new Supplementary Information Section G and Fig. S17 for Bogoliubov QPI in a new $x=0.15$ sample.

Below, the comments from the reviewers are included in black *italic* typeface. Our responses are in regular blue typeface. The changes to the text in the revised manuscript are discussed or quoted in red.

Response to the Reviewer #1

This manuscript addresses the long-standing open question regarding the origin of the chiral charge density wave (CDW) order, the so-called "parent" state in kagome metals and superconductors, which represents a central unresolved issue in low-temperature kagome physics. Using spectroscopic-imaging scanning tunneling microscopy (SI-STM), the authors investigate Ti-doped CsV₃Sb₅ with suppressed CDW order and report the discovery of a parent chiral-nematic Fermi liquid state, supported by a set of key experimental observations. Overall, this work fills a critical knowledge gap in quantum materials research and is highly suitable for publication in Nature Communications. Nevertheless, several points require further clarification and refinement to strengthen the scientific rigor and persuasiveness of the main conclusions.

Response: We sincerely thank the Reviewer for the highly positive assessment of our work, particularly for recognizing that it addresses the long-standing open question regarding the origin of the chiral CDW. We also appreciate the Reviewer's comment that our study "fills a critical knowledge gap" and is "highly suitable for publication in *Nature Communications*." We are grateful for the Reviewer's valuable comments and constructive suggestions, which we address point by point below.

Comment 1: *The evolution of superconductivity relative to the proposed parent state needs explicit discussion. While the manuscript centers on the "parent" state in kagome metals and superconductors, its connection to superconductivity remains largely unaddressed. As shown in Fig. S9, a full U-shaped gap feature is observed. The authors should clarify the evolution of the superconducting gap across different Ti doping levels, specifically for $x=0, 0.05, 0.15, 0.27$. A direct, systematic comparison of superconducting behavior as a function of Ti concentration must be elaborated in detail.*

Response 1: We thank the Reviewer for the suggestion to discuss the evolution of superconductivity. In our previous work [ref 29, Yang, H. *et al. Science Bulletin* **67**, 2176–2185 (2022)], we systematically investigated its dependence on Ti doping, and we briefly summarize the key results here (Fig. R1 and new Fig. S11). In pristine CsV₃Sb₅ ($x = 0$), the superconducting gap exhibits a V-shaped spectrum (Fig. R1a) with a diamagnetism onset transition temperature T_c of ~ 3.5 K. Upon Ti doping, superconductivity is initially suppressed at low doping ($x = 0.05$), with T_c decreasing to ~ 2.5 K. With further doping, the gap evolves into a U-shaped spectrum, accompanied by an increase in T_c to ~ 3.5 K ($x = 0.15$) and ~ 3.7 K ($x = 0.27$).

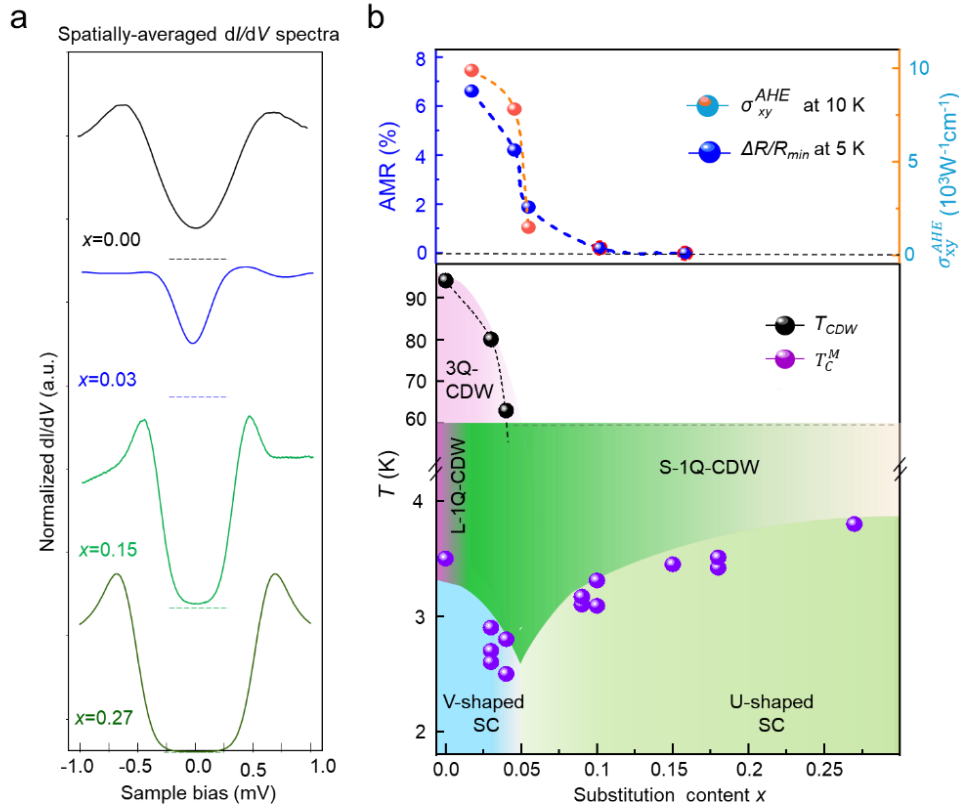
The resulting phase diagram displays two superconducting domes (Fig. R1b): the first, associated with long-range CDW order and a V-shaped gap, and the second, emerging after the suppression of long-range CDW, characterized by a U-shaped gap.

Within this context, our present results show that the chiral-nematic Fermi liquid state persists across both doping regimes and provides the electronic background from which the ordered phases develop. In the undoped and lightly doped regime ($x = 0$ and $x = 0.05$), CDW order, electronic nematicity, and superconductivity with V-shaped gap develop on the background of this symmetry-broken "parent" electronic state. In addition, in the highly Ti-doped regime ($x = 0.15$ and $x = 0.27$), superconductivity with a U-shaped gap develops directly from the "parent" chiral-nematic state without accompanying long-range CDW order.

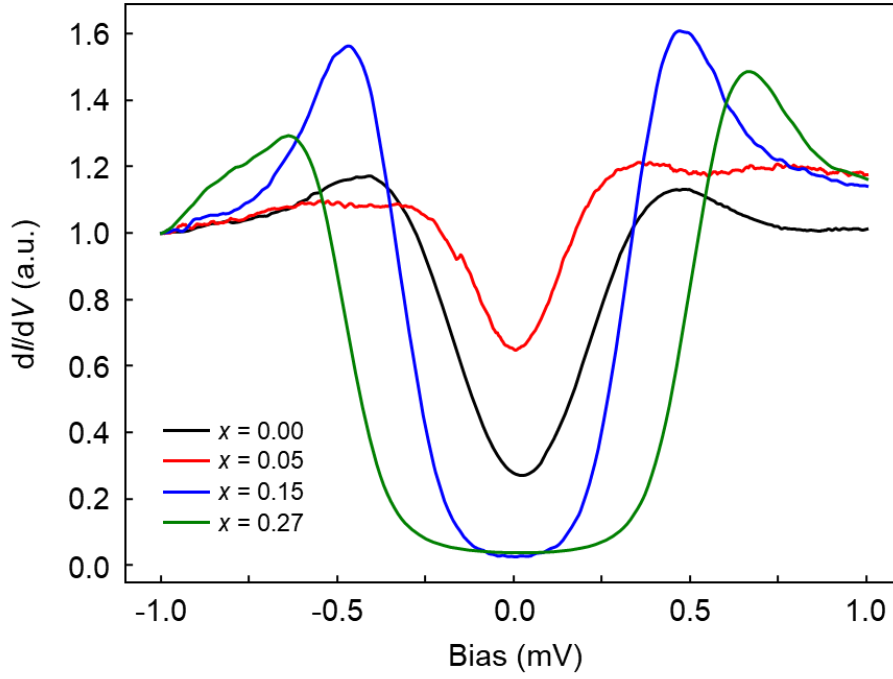
To further clarify this evolution, we have now added a new supplementary Section A discussing the

doping dependence of superconductivity in Ti-doped CsV_3Sb_5 , together with additional superconducting tunneling spectra shown in the newly added Fig. S11. We have revised the manuscript accordingly.

“...consistent with the observation of the chiral CDW phases of the lightly Ti doped sample at $x = 0.05$ (Fig. 4a-e) and the two undoped samples at $x = 0$ (Supplementary Figs. S6 and S7). Therefore, CDW order, electronic nematicity, and superconductivity with V-shaped gap (Fig. S11) emerge from this symmetry-broken “parent” Fermi liquid state. In addition, in the highly Ti-doped regime, superconductivity with a U-shaped gap (Fig. S11) develops directly from the “parent” chiral-nematic Fermi liquid state without accompanying long-range CDW order. Moreover, the chirality defined by...”



Response Fig. R1. Evolution of the superconducting gap and two distinct phases. **a**, Spatially-averaged dI/dV spectra obtained on the Sb surfaces of the CsV_3Sb_5 (black curve) and $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ samples ($x = 0.03, 0.15$ and 0.27 , corresponding to blue, green, and dark green curves, respectively), showing a transition from V-shaped to U-shaped symmetry through Ti substitution. The horizontal dash lines highlight the positions of zero density of states for each curve. **b**, Phase diagram of the $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ crystals. In the V-Shaped SC regime, T_{CDW} is significantly reduced with increasing x . The amplitude of the anomalous Hall conductivity σ_{xy}^{AHE} and AMR (%), is dramatically decreased, that is, long-range CDW, AHE and nematicity were simultaneously suppressed. In contrast, in the U-shaped SC regime where AHE, long-range CDW, and nematicity are undetectable, the superconductivity coexisting with short-range CDWs tends to gradually recover: T_c^M rises to ~ 3.5 K at $x = 0.15$, and showing a slight increase to 3.7 K at $x = 0.27$. This figure is from our previous work [Yang, H. *et al. Science Bulletin* **67**, 2176–2185 (2022)].



New Fig. S11. Evolution of the superconducting gap upon Ti doping. Spatially-averaged dI/dV spectra obtained on the Sb surfaces of the CsV_3Sb_5 (black curve) and $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ samples ($x=0.00$, 0.05, 0.15 and 0.27, corresponding to red, blue, and green curves, respectively), showing a transition from V-shape to U-shape symmetry through Ti substitution.

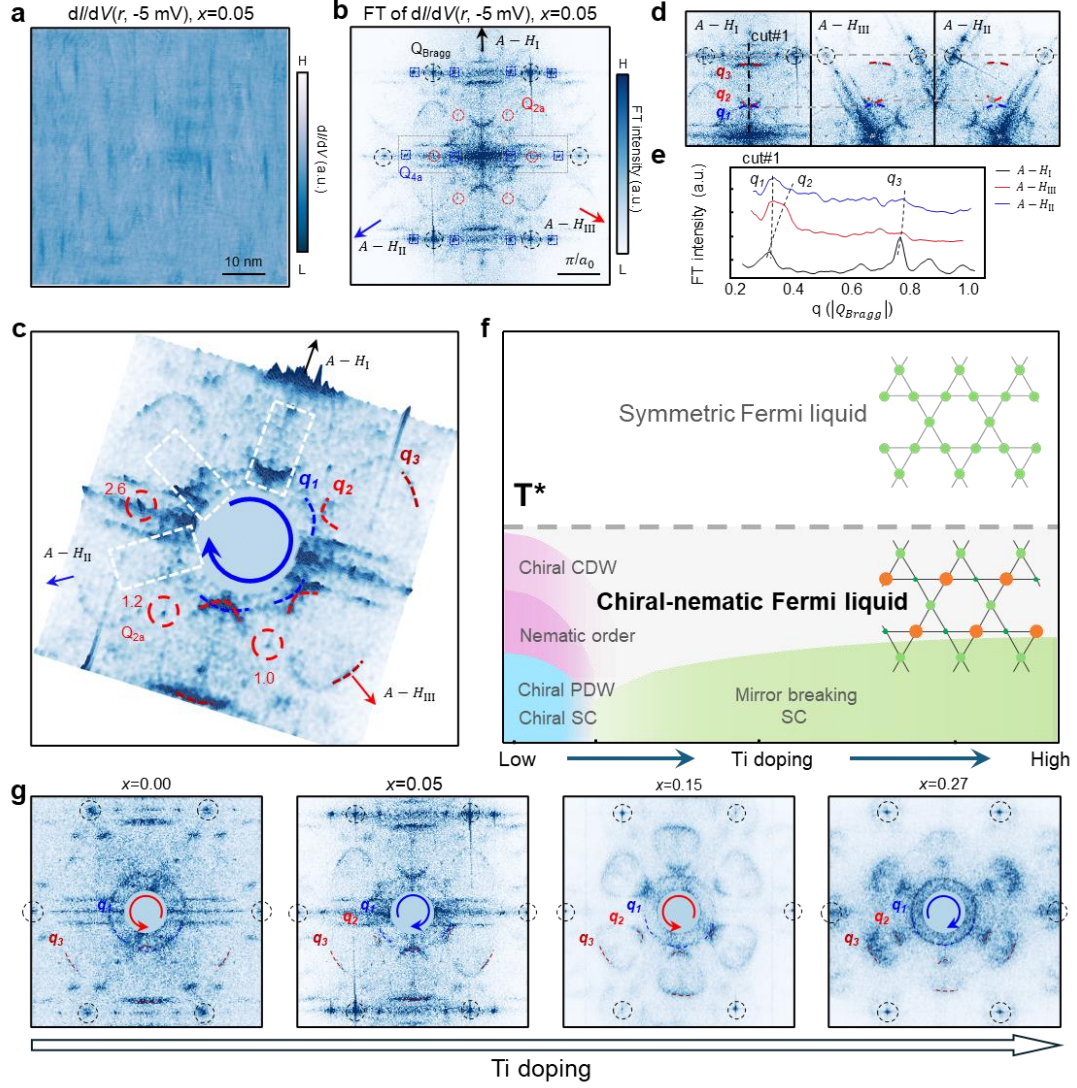
Comment 2: *I recommend that the authors directly compare the evolution of quasiparticle interference (QPI) spectra across different Ti doping levels in a main-text figure. This would greatly assist readers in tracking the evolution of chiral-nematic order and reinforce the key experimental narrative.*

Response 2: We thank the Reviewer for this helpful suggestion. We agree that a direct comparison of QPI across different Ti doping levels improves clarity in tracking its evolution and strengthens the overall experimental narrative.

Accordingly, we have added a new Fig. 4g in the main text, which summarizes the QPI evolution at different Ti doping levels. This new figure allows the evolution of the rotational and mirror symmetry breaking behavior to be tracked systematically across the phase diagram.

We have also included the discussion of Fig. 4g in the revised manuscript:

“...where the chiral-nematic Fermi liquid emerges from the high-temperature symmetry phase at the temperature T^* due to electron correlations. The low-energy QPI patterns across different Ti doping levels consistently exhibit rotational and mirror symmetry breaking (Fig. 4g), indicating the robustness of the underlying chiral-nematic Fermi liquid state across the phase diagram. Below T^* , the cascade of exotic CDW and SC phases could originate from the parent chiral-nematic Fermi liquid...”



Revised Fig. 4. Observation of chiral-nematic residual Fermi surface in lightly Ti-doped CsV_3Sb_5 with CDW order. **a**, dI/dV map of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.05$), showing the presence of charge orders. $V_{\text{bias}} = -5$ mV, $I = 200$ pA, $V_{\text{lock-in}} = 0.2$ mV. **b**, FT of **(a)**, showing the presence of multiple electronic states. Black dotted circles, red dotted circles, and blue dotted rectangles mark the Bragg points, $2a_0 \times 2a_0$ CDW order, and $1a_0 \times 4a_0$ stripes order, respectively. $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions are indicated by arrows. **c**, 3D plot of the zoomed-in FT in **(b)**, highlighting the QPI pattern. The curved arrow denotes the chirality of QPI patterns. White dashed rectangles highlight the evolving separation between q_1 and q_2 vectors. The intensity ratios of the $2a_0 \times 2a_0$ CDW peaks as marked by red dotted circles is labeled. The central region is masked for clarity. **d**, QPI pattern along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions, respectively, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI pattern. **e**, Line profiles (cut#1) along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions in **(b)**, respectively, showing the chirality of $q_i^{H_m}$ ($i = 1, 2, 3; m = \text{I, II, III}$). The different lengths of scattering vectors are indicated by dotted curves. **f**, Schematic phase diagram for kagome metals and superconductors, illustrating the emergence of the chiral-nematic Fermi liquid state as a parent state in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$. Inset shows a uniform charge distribution (upper right) corresponding to symmetric Fermi liquid and an intra-cell, sublattice charge order (lower right) corresponding to chiral-nematic Fermi liquid. **g**, Summary of the QPI evolution across different Ti doping levels.

Comment 3: Structural characterization data for different Ti doping concentrations should be provided. For instance, the authors should specify the type and density of doping-induced defects, along with supporting evidence such as XRD measurements of lattice parameter variations or TEM characterizations. Additionally, it is necessary to clarify whether this "parent phase" manifests distinct experimental signatures in the resistance – temperature curves of Ti-doped CsV₃Sb₅ samples.

Response 3: We thank the Reviewer for this valuable suggestion. The structural characterization of CsV_{3-x}Ti_xSb₅ at different Ti doping levels has been systematically investigated in our previous work [ref 29, Yang, H. *et al. Science Bulletin* **67**, 2176–2185 (2022)]. We now summarize the representative structural and transport characterization results in Fig. R2.

Figures R2a–d present scanning transmission electron microscopy (STEM) results for the $x = 0.15$ sample. Electron energy-loss spectroscopy (EELS, Fig. R2a) confirms a Ti:V ratio of ~5%. The high-angle annular dark-field (HAADF) image (Fig. R2b), overlaid with the structural model, reveals a well-ordered crystalline structure without noticeable defects. Atomic-resolution chemical mapping (Figs. R2c,d) shows that Ti atoms predominantly substitute at V sites within the VSb1 layer.

The representative X-ray diffraction (XRD) result confirms the high-quality of the CsV_{3-x}Ti_xSb₅ single crystal (Fig. R2e). Energy-dispersive X-ray spectroscopy (EDS, Fig. R2f) yields a Ti concentration of $x = 0.15$ (~5% V substitution). The lattice parameters ($a = b = 5.521$ Å, $c = 9.336$ Å) are slightly reduced compared to pristine CsV₃Sb₅, corresponding to changes of ~0.4% (a and b) and ~0.1% (c), indicating negligible chemical pressure.

In STM measurements, Ti dopants appear as dark spots on the Sb2-terminated surface, consistent with substitution at the underlying V sites. These features are absent in pristine samples and increase in density with Ti content (Figs. R2g,h). Statistical analysis of the topographic height maps (Fig. R2g, bottom panels) shows that the distributions can be fitted by two Gaussian components corresponding to dopant and normal height regions. The extracted area fractions of dopant-related features increase systematically with Ti concentration.

We have also carefully examined the transport behavior of Ti-doped CsV₃Sb₅. Representative resistance–temperature curves for pristine and $x = 0.15$ samples are shown in Fig. R2i. In both cases, the dominant anomaly corresponds to the CDW transition, visible as a kink in the resistance and more clearly in its temperature derivative (Fig. R2j). Beyond the CDW-related feature, no additional pronounced anomaly attributable specifically to the proposed chiral-nematic electronic state is clearly resolved in the transport data.

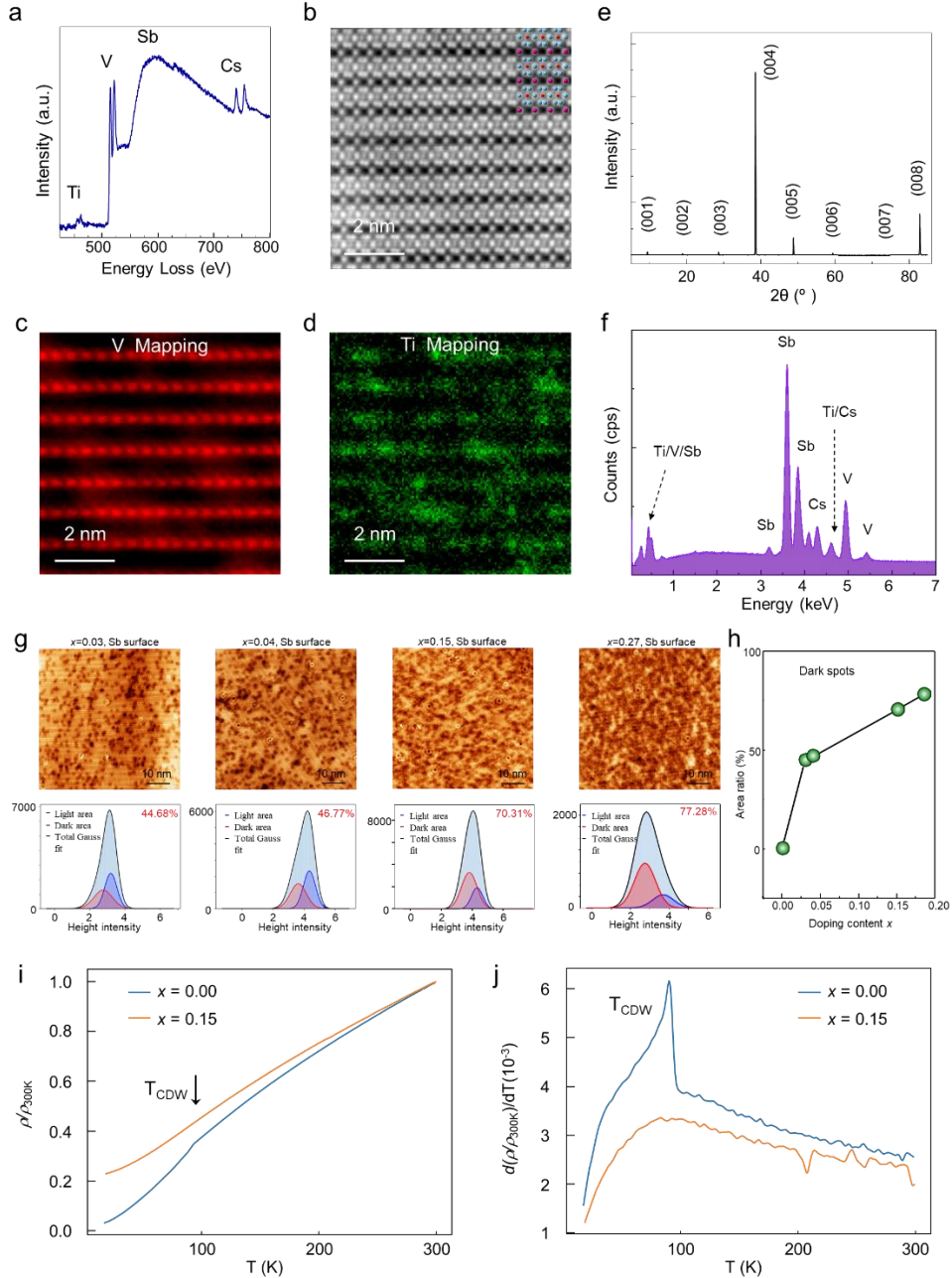
This suggests that the chiral-nematic state primarily manifests through subtle momentum-space electronic symmetry breaking rather than through a strong thermodynamic or transport signature. Interestingly, recent magnetic torque measurements [Ref. 28, Asaba, T. *et al. Nat. Phys.* **20**, 40–46 (2024)] reported evidence for spontaneous rotational symmetry breaking above the bulk CDW transition and below a characteristic temperature of approximately 130 K, which may be consistent with the symmetry-breaking behavior observed in our QPI measurements. However, at present, the precise onset temperature T^* of this symmetry-broken electronic state remains to be determined more directly using temperature-dependent microscopic probes. Techniques such as nano-ARPES or spatially resolved spectroscopy capable of resolving individual chiral domains may provide further insight in future studies.

Further details of the structural and transport characterization are provided in Ref. [29], which has now been explicitly cited and highlighted in the revised manuscript as below:

“...It has been shown that CsV₃Sb₅ can be doped by Ti that substitutes V sites within the kagome layer while preserving the crystal structure, forming CsV_{3-x}Ti_xSb₅²⁹, where x is the Ti concentration. In STM topography, the Ti dopants appear as dark features beneath the Sb-terminated surface (Fig. 1d)²⁹. To

probe the electronic structure and reveal the electronic state without translation symmetry breaking...”

“...which is significantly higher than the highest CDW transition temperature $T_{CDW} \sim 90$ K in the undoped CsV_3Sb_5 . While the resistance–temperature curves do not exhibit a pronounced additional anomaly beyond the CDW-related feature²⁹, recent thermodynamic torque measurements²⁸ have reported evidence for spontaneous rotation symmetry breaking above the bulk CDW transition and below a characteristic temperature around 130 K...”



Response Fig. R2. Structural characterization for Ti doped CsV_3Sb_5 . **a**, Background-subtracted EELS spectrum showing clear Ti, V, Sb, and Cs signals. Quantification of the Ti and V signals shows an atomic ratio of Ti:V $\sim 5.3:94.7$. **b**, STEM-HAADF Z-contrast image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ crystal viewed along the [100] projection, with the atomic structural models overlaid. The Cs, V, Sb atoms are shown in purple, red, and light blue, respectively. **c-d**, Atomic-resolution chemical mapping acquired *via* STEM-EELS spectrum imaging, with the simultaneously acquired V mapping shown in red (**c**) and Ti

mapping shown in green (**d**). **e**, Typical XRD pattern of the $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) crystal. **f**, EDS of the crystal showing the stoichiometric ratio of Cs:V:Ti:Sb = 0.96:2.85:0.15:4.95. **g**, top panel: typical large-scale ($60 \text{ nm} \times 60 \text{ nm}$) STM images of Sb surface of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.03$), ($x=0.04$), ($x=0.15$), and ($x=0.27$) Ti-doped samples. Bottom panel: statistical analysis of height map in the corresponding STM image. Each height map can be fitted by two Gaussian peaks which correspond to the dark spots and normal height regions. The area ratios of dark spots are 44.68%, 46.77% and 70.31% for the $x=0.03$, $x=0.04$ and $x=0.15$ doped sample, respectively. **h**, Relationship between the doping content and the area ratio of the dark spots in the STM images, indicating that the dark spots in the STM images originate from Ti dopant in the underlying VSb layer. **i**, The normalized electrical resistivity ρ curve of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ crystals of $x = 0.00$ and 0.15 . **j**, The derivative electrical resistivity $d\rho/dT$ curve of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ crystals of $x = 0.00$ and 0.15 .

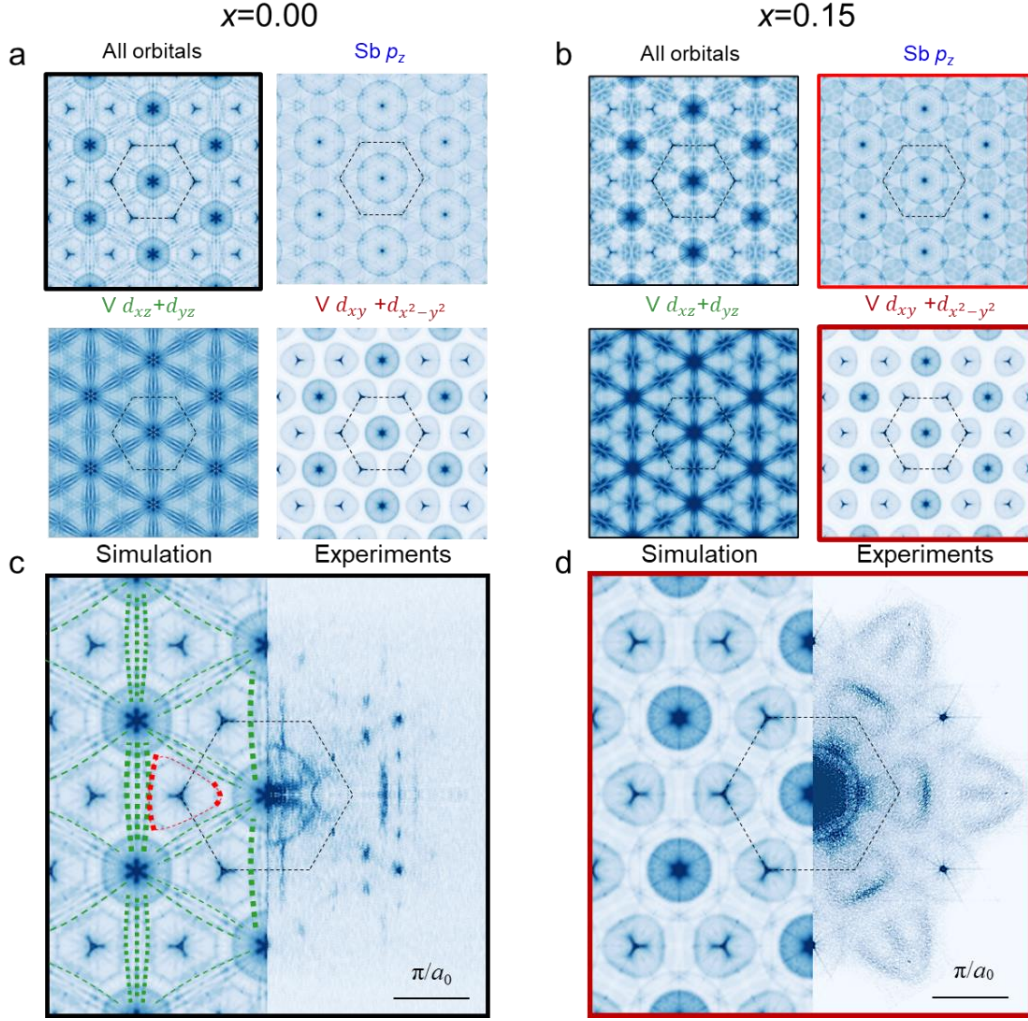
Comment 4: *The authors mention the observation of "residual chiral-nematic QPI features" in samples with chiral CDW order, which they use to argue that CDW-induced exotic states derive from the chiral-nematic Fermi liquid. To solidify the causal relationship between the parent state and CDW-stabilized phases, the authors should briefly clarify how these residual QPI signatures differ from those in the parent state, for example, in terms of spectral intensity, spatial distribution, or energy dependence.*

Response 4: We thank the Reviewer for this insightful suggestion. We have carefully examined the differences between the residual QPI features in pristine CsV_3Sb_5 with chiral CDW order and the QPI patterns in Ti-doped samples without long-range CDW in our previous work [ref 22, Huang, Z. *et al. Phys. Rev. Lett.* **134**, 56001 (2025)]. For clarity, we summarize the key results here and present representative data in Fig. R3.

Combining QPI measurements with DFT calculations, we find that the most prominent distinction lies in the emergence of a unidirectional, stripe-like QPI feature in the CDW phase (Fig. R3c), which originates from out-of-plane V d orbitals (Fig. R3a). In contrast, this stripe-like feature is absent in Ti-doped samples without long-range CDW, where the QPI patterns are dominated by a central circular feature and outer triangular features arising from Sb p_z orbitals and in-plane V d_{xy} and $d_{x^2-y^2}$ orbitals (Figs. R3b,d). In terms of spectral intensity, the stripe-like feature in the CDW phase exhibits enhanced spectral weight relative to the triangular features (Fig. R3c), indicating that the CDW significantly gaps the in-plane V d_{xy} and $d_{x^2-y^2}$ states. In contrast, in the non-CDW phase, the triangular QPI features remain prominent (Fig. R3d) and exhibit clear rotational and mirror symmetry breaking. In addition, the unidirectional QPI associated with out-of-plane V orbitals in the CDW phase recovers isotropic intensity at energies of 14 meV, as reported in Ref. 13 [Zhao, H. *et al. Nature* **599**, 216–221 (2021)]. In contrast, QPI features associated with out-of-plane V d orbitals are absent across the entire low-energy range in the non-CDW phase [ref 22].

Despite these differences, the residual QPI vectors discussed in the present work (e.g., q_1 , q_2 , and q_3) share the same orbital origin as those in the non-CDW phase. These features become more pronounced in lightly doped samples ($x = 0.05$; Figs. 4b, c), where the CDW is partially suppressed. We attribute these residual QPI signatures to ungapped portions of the parent Fermi surface, and note that their broken rotational and mirror symmetries are consistent with those observed in the non-CDW phase, reflecting the underlying chiral-nematic Fermi liquid. This provides direct evidence that the CDW-stabilized phases inherit their electronic structure from the parent chiral-nematic Fermi liquid.

Taken together, these results indicate that the CDW primarily reconstructs, rather than replaces, the underlying chiral-nematic Fermi liquid, and that the residual QPI features provide a direct fingerprint of this parent state.



Response Fig. R3. QPI comparison between pristine CsV_3Sb_5 and $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$). **a-b**, The simulated QPI patterns based on all the orbitals, $\text{Sb } p_z$ orbital, $V d_{xz}$ and d_{yz} orbitals and $V d_{xy} + d_{x^2-y^2}$ orbitals for pristine CsV_3Sb_5 (**a**) and $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) (**b**). **c**, The residual QPI patterns (residual circle and triangular pattern) in pristine CsV_3Sb_5 agree well with the simulated $\text{Sb } p_z$ orbitals and $V d_{xy} + d_{x^2-y^2}$ orbitals QPI pattern (left). **d**, The measured QPI patterns (right) in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) agree well with the simulated $\text{Sb } p_z$ orbitals and $V d_{xy} + d_{x^2-y^2}$ orbitals QPI pattern (left).

We have discussed the differences and similarities between these two QPI features and further discussed the causal relationship between the parent state and CDW-stabilized phases in the revised manuscript:

“...that closely resemble the corresponding patterns observed in the $x = 0.15$ sample without CDW order. According to previous studies²², although the unidirectional QPI stripes originate primarily from out-of-plane V orbitals, the triangular and circular QPI patterns arise predominantly from the in-plane V orbitals and $\text{Sb } p_z$ orbitals, respectively, and therefore share the same electronic orbital origin as the corresponding features observed in the $x = 0.15$ sample. As revealed by the 3D zoom-in FT plot (Fig. 4c)...”

“...which closely resembles the behaviors observed in the CDW-free sample at $x=0.15$. In addition, these residual QPI features share the same electronic orbital origin as those observed in the non-CDW phase, reflecting the similar underlying chiral-nematic Fermi liquid state. These observations of rotation and mirror symmetry breaking suggest that the CDW order may have emerged from the chiral-nematic Fermi liquid parent state...”

Comment 5: *Although the work presents novel findings, it could better contextualize this study within existing literature on nematic Fermi liquids and chiral symmetry breaking in kagome materials. For instance, explicitly distinguishing this chiral-nematic Fermi liquid state from previously reported nematic phases (e.g., rotational symmetry breaking versus mirror symmetry breaking) would more effectively highlight the conceptual novelty and advance of this discovery.*

Response 5: We thank the Reviewer for this valuable suggestion. We agree that placing our results in the context of previously reported nematic and chiral phases in kagome materials helps to better highlight the conceptual advance of this work.

Previous studies of chirality in kagome superconductors AV_3Sb_5 have primarily focused on the 2×2 CDW state, where chirality manifests as an intensity imbalance among the three symmetry-related CDW wave vectors in Fourier-transformed data, corresponding to mirror symmetry breaking [Jiang, Y.-X. *et al. Nat. Mater.* **20**, 1353–1357 (2021); Xing, Y. *et al. Optical manipulation of the charge-density-wave state in RbV_3Sb_5 . Nature* **631**, 60–66 (2024)]. In addition, signatures such as the anomalous Hall effect and time-reversal symmetry breaking have been observed below the CDW transition temperature, suggesting a connection between the chiral CDW and flux phases [Yu, F. H. *et al. Phys. Rev. B* **104**, L041103 (2021); Mielke, C. *et al. Nature* **602**, 245–250 (2022); Guo, C. *et al. Nature* **611**, 461–466 (2022)].

Nematicity reported in earlier works is mainly associated with anisotropy in spectral intensity. For example, (i) CDW-driven nematicity has been identified through C_2 -symmetric intensity variations of the 2×2 CDW peaks in Fourier space [Nie, L. *et al. Nature* **604**, 59–64 (2022)], and (ii) unidirectional coherent quasiparticle interference has been observed as a reduction of the C_6 -symmetric QPI intensity to C_2 symmetry [Zhao, H. *et al. Nature* **599**, 216–221 (2021); Li, H. *et al. Nat. Phys.* **18**, 265–270 (2022)]. These effects are primarily reflected in QPI spectral weight and tend to weaken with increasing temperature or Ti doping.

In contrast, our work identifies a chiral-nematic Fermi liquid state based on the momentum structure and dispersion of QPI vectors, rather than their spectral intensity. Specifically, we observe both rotational and mirror symmetry breaking directly in the scattering wave vectors, indicating an intrinsic modification of the underlying electronic structure. Importantly, these symmetry-breaking features are robust against Ti doping and coexist with the CDW state, suggesting a higher characteristic energy scale than previously reported CDW-chirality or intensity nematicity.

Therefore, our results suggest the presence of an underlying chiral-nematic electronic state that may provide the symmetry-breaking electronic background from which the chiral CDW and CDW-associated nematic phases subsequently develop. This distinction highlights the conceptual advance of the present work and provides new insight into the microscopic origin of chirality and nematicity in kagome materials.

We have clarified this distinction in the revised manuscript to more explicitly highlight the difference between our chiral-nematic Fermi liquid and previously reported chiral and nematic phases.

“...provide microscopic evidence for a novel correlated electron state – a chiral-nematic Fermi liquid – already present above the CDW transition. Distinct from previously reported chiral CDW phases^{20,31} and CDW-driven nematic state^{12,13,15}, which are manifested as spectral-weight anisotropy in $\mathbf{q}$ -space and vanish upon chemical doping^{22,29}, the observed symmetry breaking is reflected in the momentum-space electronic structure itself and remains robust across both CDW and non-CDW regimes. These

observations suggest the existence of an underlying symmetry-broken electronic state that may provide the electronic background from which the multiple ordered phases emerge, offering new insight into the microscopic origin of chirality, nematicity, and correlated electronic order in kagome metals.”

In summary, we believe we have addressed all comments and questions raised by the Reviewer, adding new data and discussions. Once again, we sincerely thank the Reviewer for the insightful, and constructive comments, which have helped us to further strengthen the manuscript.

Response to the Reviewer #2

The paper by Z. Huang et al., presents interesting scanning tunneling microscopy results on the Kagome metal system $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$. In particular, the present detailed quasi-particle interference (QPI) spectra for different levels of Ti doping, including $x = 0.15$, where the CDW is suppressed. They find that the peaks in QPI maps, which are linked to scattering vectors spanning constant energy contours, exhibit features consistent with a nematic chiral-symmetry breaking the normal metallic phase, which they argue is the true “parent” phase from which chiral CDW and superconducting orders emerge. The results are compared with simulations based on a simplified joint density-of-states model with a band structure derived from ab initio simulations. The authors' results, if correct, suggest that the system exhibits a degree of rotational and mirror-symmetry breaking at all Ti-doping levels. This finding could be used to constrain models for the chiral CDW order in these materials.

Overall, I found the work to be very interesting, and the paper is well written. The subject matter is also very timely, considering the community's strong interest in Kagome metals. For these reasons, I am inclined to view the paper as appropriate for Nature Communications if the authors can satisfactorily address the comments and questions provided. I, therefore, suggest that the authors be given a chance to revise and resubmit this work for further consideration.

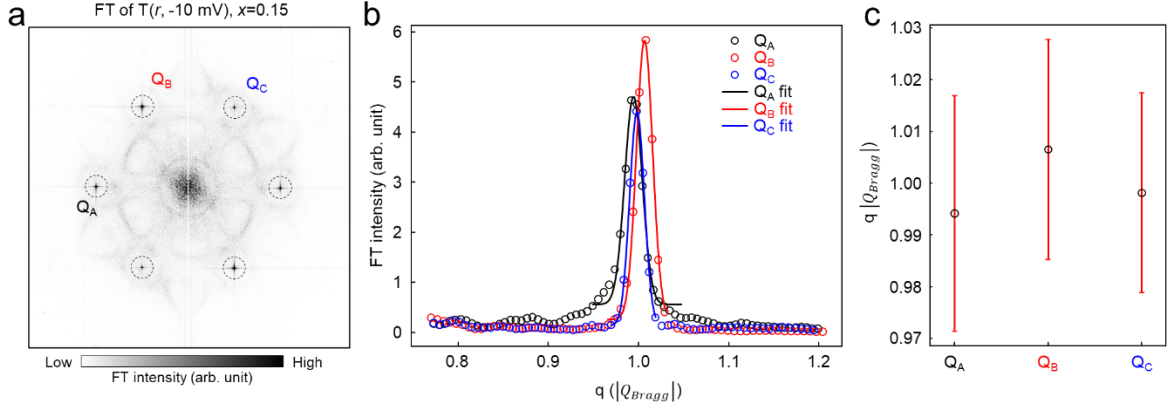
Response: We sincerely thank the Reviewer for the concise summary and highly positive assessment of our work, describing it as “very interesting,” “well written,” and “very timely,” and therefore “appropriate for *Nature Communications*.” We also greatly appreciate the Reviewer's valuable comments and constructive suggestions, which we address point by point below.

Comment 1: *The authors use the peak locations of several QPI vectors as evidence for the symmetry breaking. However, they also state that they align the Bragg peaks in the spectra after 60 and 120 degree rotations. Does this mean that the Bragg peaks (and therefore underlying lattice structure) also don't follow the expected lattice symmetries? Can they please clarify this matter?*

Response 1: We thank the Reviewer for this important comment. In Fig. 2b of the main text, we apply an affine transformation to align the Bragg peaks after 60° and 120° rotations. This procedure is commonly used to correct for instrumental drift and other experimental distortions [Gu, Q. *et al. Nature* **618**, 921–927 (2023)] and does not affect the intrinsic electronic structure. In this work, we primarily focus on symmetry breaking in the electronic structure.

To clarify the Reviewer's query regarding lattice symmetry, we analyze the lattice symmetry directly from the raw (uncorrected) data, as shown in a new Fig. S12. We compare the three Bragg vectors Q_A , Q_B , and Q_C from the Fourier-transformed topography (Fig. S12a), and show their line profiles (Fig. S12b). Gaussian fitting of the peak positions (Fig. S12c) yields variations in the Bragg vector magnitudes of less than ~1% relative to their average value. Considering the full width at half maximum as an estimate of uncertainty, these differences fall within the error bars, indicating that any deviation from ideal lattice symmetry is negligible. The standard error of the extracted peak positions is ~0.5%.

In contrast, the anisotropy observed in the QPI wave vectors is significantly larger. For example, the variation in q_2 reaches up to ~3% near the Fermi level, exceeding the uncertainty associated with Bragg peak analysis. This suggests that the observed mirror and rotational symmetry breaking is primarily reflected in the electronic structure.



New Fig. S12. Lattice structure symmetry analysis. **a**, Fourier-transformed topography (same as Fig. 1e), showing the Bragg peaks Q_A , Q_B , and Q_C . **b**, Lengths of the Bragg vectors Q_A , Q_B , and Q_C . The peaks are fitted with Gaussian function. The unit of the length represents their average value. **c**, Extracted lengths of Q_A , Q_B , and Q_C . Error bars represent the full width at the half maximum (FWHM) of the fitted Gaussian peaks.

We have incorporated the discussion of this analysis into the new Supplementary Information section B:

“We further analyze the lattice symmetry directly from the raw (uncorrected) data, as shown in a Fig. S12. We compare the three Bragg vectors Q_A , Q_B , and Q_C from the Fourier-transformed topography (Fig. S12a), and show their line profiles (Fig. S12b). Gaussian fitting of the peak positions (Fig. S12c) yields variations in the Bragg vector magnitudes of less than $\sim 1\%$ relative to their average value. Considering the full width at half maximum as an estimate of uncertainty, these differences fall within the error bars, indicating that any deviation from ideal lattice symmetry is negligible. The standard error of the extracted peak positions is $\sim 0.5\%$.

In contrast, the anisotropy observed in the QPI wave vectors is significantly larger. For example, the variation in q_2 reaches up to $\sim 3\%$ near the Fermi level, exceeding the uncertainty associated with Bragg peak analysis. This suggests that the observed mirror and rotational symmetry breaking is primarily reflected in the electronic structure.”

Comment 2: *The comparison to the theory simulations needs further justification and discussion. The authors are essentially comparing the QPI patterns against a JDOS calculation and the ab initio band structure at a fixed $K_z = \pi$. No justification for this value is given, and there is no reason to expect that electrons tunnel into the system at a fixed k_z value. Note that the theory for tunneling into a 3D band structure has been worked out [see Rhodes et al., PRB 107, 045107 (2023)]. Why not perform calculations for the full band structure? Why is K_z the right momentum here? How robust are the conclusions to different values K_z ?*

Response 2: We thank the Reviewer for raising this important point. Our use of the $k_z = \pi$ Fermi surface is motivated by experimental evidence indicating that AV_3Sb_5 kagome materials are quasi-two-dimensional, with weak interlayer coupling. In particular, transport measurements show a large resistivity anisotropy ($\rho_c/\rho_{ab} \sim 600$) [Ortiz, B. R. et al. *Phys. Rev. Lett.* **125**, 247002 (2020)], consistent with a predominantly two-dimensional electronic structure.

Angle-resolved photoemission spectroscopy (ARPES) measurements further reveal a Fermi surface with negligible k_z dispersion, and show good quantitative agreement with calculated band structures at $k_z = \pi$ [Ortiz, B. R. *et al. Phys. Rev. Lett.* **125**, 247002 (2020); Luo, H. *et al. Nat. Commun.* **13**, 273 (2022); Hu, Y. *et al. Sci. Bull.* **67**, 495–500 (2022); Liu, Z. *et al. Phys. Rev. X* **11**, 41010 (2021)]. Based on these observations, the $k_z = \pi$ Fermi surface provides a reasonable and experimentally supported approximation for the dominant electronic states contributing to QPI.

In addition, in our previous work [ref 22, Huang, Z. *et al. Phys. Rev. Lett.* **134**, 56001 (2025)], we performed detailed comparisons between QPI measurements and orbital-resolved DFT calculations (see Fig. R3 below), and found good agreement when using the $k_z = \pi$ Fermi surface for both undoped ($x = 0.00$, Figs. R3a,c) and Ti-doped ($x = 0.15$, Figs. R3b,d) samples. This consistency suggests that the main QPI features are captured within this approximation.

We note that, while tunneling in principle involves contributions from a range of k_z values, the weak k_z dispersion in this system implies that the essential features of the QPI are not strongly sensitive to k_z . Therefore, the use of a representative $k_z = \pi$ slice provides a reasonable description for analyzing the symmetry properties of the electronic structure. While a fully k_z -integrated tunneling calculation would be of considerable interest, we believe it is beyond the scope of the present study and represents an important direction for future work.

We have cited the theory for tunneling into a 3D band structure and added discussion to better justify the choice of $k_z = \pi$ Fermi surface when comparing with theory in the Methods.

“The approximation of a fixed k_z , without a full treatment of tunneling into a three-dimensional band structure⁴⁷, is justified by the quasi-two-dimensional electronic structure and weak k_z dispersion observed experimentally⁴⁸. In particular, the calculated Fermi surface at $k_z = \pi$ shows good quantitative agreement with the experimental data^{22,48,49} and is therefore used for comparison with theory.”

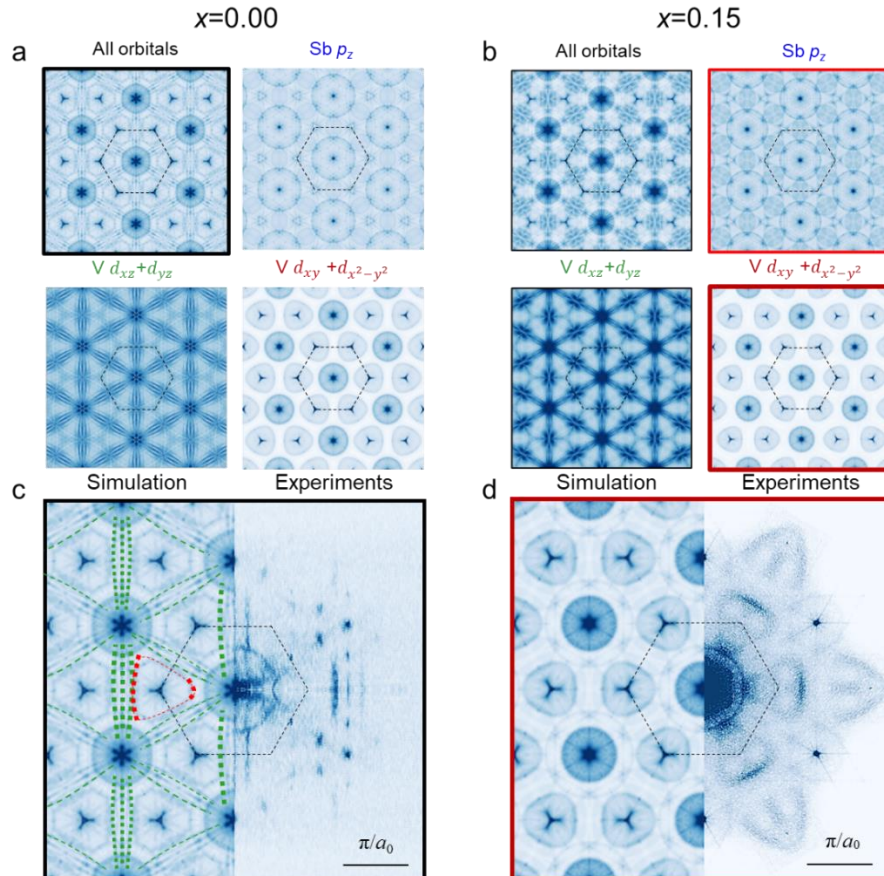


Fig. R3. QPI comparison between pristine CsV₃Sb₅ and CsV_{3-x}Ti_xSb₅ (x=0.15). **a-b**, The simulated QPI patterns based on all the orbitals, Sb p_z orbital, V d_{xz} and d_{yz} orbitals and V $d_{xy} + d_{x^2-y^2}$ orbitals for pristine CsV₃Sb₅ (**a**) and CsV_{3-x}Ti_xSb₅ (x=0.15) (**b**). **c**, The residual QPI patterns (residual circle and triangular pattern) in pristine CsV₃Sb₅ agree well with the simulated Sb p_z orbitals and V $d_{xy} + d_{x^2-y^2}$ orbitals QPI pattern (left). **d**, The measured QPI patterns (right) in CsV_{3-x}Ti_xSb₅ (x=0.15) agree well with the simulated Sb p_z orbitals and V $d_{xy} + d_{x^2-y^2}$ orbitals QPI pattern (left).

Comment 3: *Related to the above point, I would like the authors to assess the role of the impurities themselves more thoroughly. Why is it okay to ignore the scattering potential? How do the authors know that the impurities are causing some of the symmetry breaking they are observing in the QPI? Some analysis of the real-space density modulations near the impurities, along with a discussion of the dominant impurities and how they affect the structure, might help address this issue.*

Response 3: We thank the Reviewer for this important question.

From a theoretical perspective, the QPI signal, $P(q, E) \propto g(q, E)$, can be expressed as [Allan, M. P. *et al. Nat. Phys.* **9**, 221–224 (2013); Capriotti, L., Scalapino, D. J. & Sedgewick, R. D. *Phys. Rev. B* **68**, 14508 (2003)]:

$$P(q, E) = \frac{1}{N} \left| \frac{1}{\pi} \text{Im} \Lambda(q, E) \right|^2 |\delta \varepsilon(q)|^2,$$

where $\Lambda(q, E)$ is the convolution of Green's functions:

$$\Lambda(q, E) = \int d^2r e^{iq \cdot r} G(r, E) G(-r, E),$$

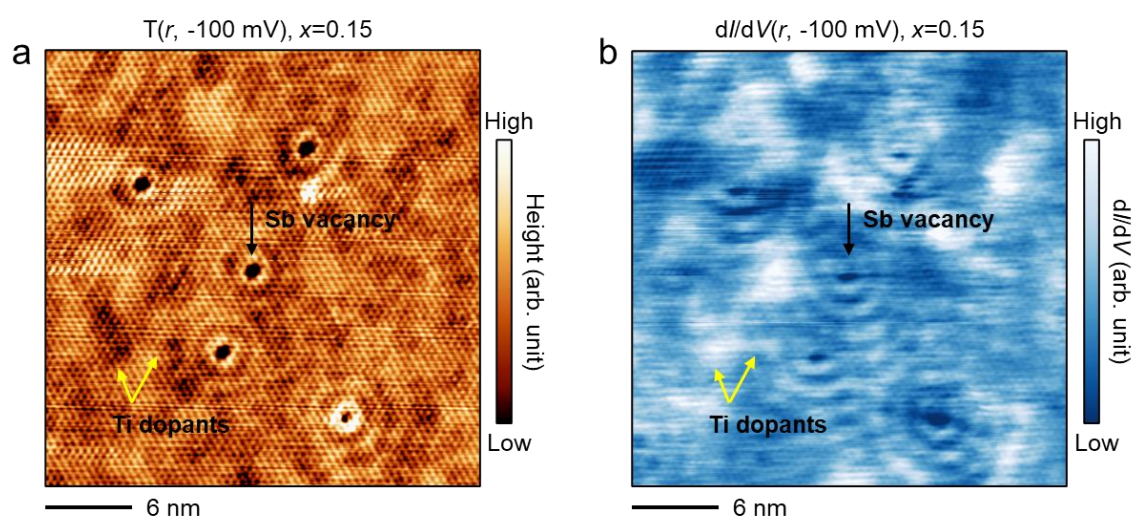
representing the ‘bare’ QPI related to the native band structure, and $|\delta \varepsilon(q)|^2$ represents the structure factor associated with the impurity scattering potential. In the weak-scattering limit and for impurity potentials that do not introduce a well-defined additional periodicity, the locations of QPI maxima are primarily determined by the underlying electronic structure, whereas the impurity structure factor mainly modulates the *spectral weight*. Therefore, the scattering potential itself does not affect our conclusions regarding the q -resolved symmetry breaking.

To further assess the role of impurities in our measurements, we analyze their real-space signatures and corresponding QPI modulations, as shown in the newly added Fig. S13. Experimentally, we identify two dominant types of impurities on the Sb-terminated surface: (i) Sb vacancies (black arrows in Fig. S13a), and (ii) Ti dopants located beneath the Sb layer (yellow arrows in Fig. S13a). The Sb vacancies exhibit nearly isotropic, hole-like features in topography, and their associated real-space local density of states modulations do not show clear symmetry breaking (Fig. S13b). The Ti dopants, as established in our previous work [ref. 29, Yang, H. *et al. Science Bulletin* **67**, 2176–2185 (2022)], substitute V sites beneath the surface and appear as dark spots in topography and bright features in dI/dV maps. Although their subsurface nature prevents direct structural imaging, their spatial signatures also do not exhibit obvious anisotropy.

These observations suggest that the dominant impurities in our samples do not introduce strong anisotropy in the scattering potential, and thus contribute approximately uniform structure factor $|\delta \varepsilon(q)|^2$ to the QPI intensity in momentum space. Consistently, we do not observe pronounced impurity-induced anisotropy in the QPI spectral weight.

Taken together, these results support that the observed symmetry breaking in the q -resolved QPI features is intrinsic to the electronic structure rather than arising from impurity effects.

We have added this discussion to the new Supplementary Information Section C to clarify the role of impurities.

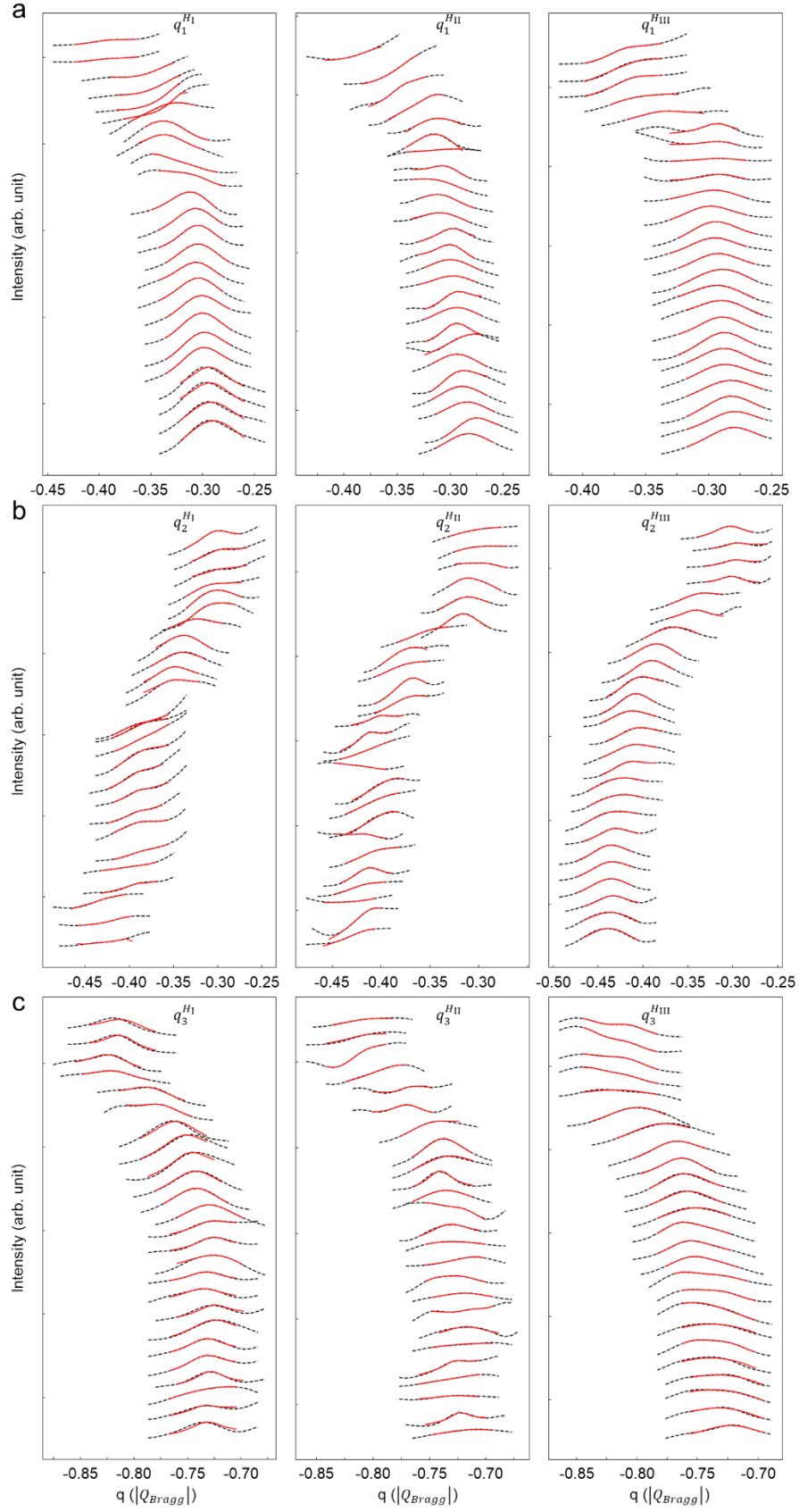


New Fig. S13. Dominant impurities. **a**, STM topography of the Sb surface, revealing circular Sb vacancies and underlying Ti dopants as the dominant impurities. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern arising from these impurities.

Comment 4: *Supplementary Figure 2 shows how the QPI peaks are fit; however, it is very difficult to read, and I am unable to gauge the quality of the fits. I think the authors should revisit this scale and expand the y-axis so the peak and the quality of the fit can be more readily judged.*

Response 4: We thank the Reviewer for pointing out this issue. We have revised the figure by rescaling and expanding the y-axis, and adjusted the displayed data range to improve the visibility of the QPI peaks and the quality of the fits, as shown in the Revised Fig. S2.

We have also added a new Supplementary Information Section D to detail the data fitting procedure.



Revised Fig. S2. Lorentzian fitting of the q -dispersions. **a-c**, Lorentz fitting (red curves) for q_1 (**a**), q_2 (**b**), and q_3 (**c**) along $A - H_I$ (left), $A - H_{II}$ (middle), and $A - H_{III}$ (right) directions. Black dotted curves are raw data.

Comment 5: *The mass enhancement values extracted from the QPI measurements appear inconsistent with the e-ph coupling values reported in Ref. 32, and this discrepancy needs to be addressed. For example, the authors claim they see features in the QPI consistent with a phonon kink but extract a mass enhancement that is less than the value of $1+\lambda$ inferred in Ref. 32. Can the authors reconcile these differences? Note that QPI measurements that have previously resolved the kinks in simple systems extract comparable mass enhancements, so this discrepancy needs to be addressed.*

Response 5: We thank the Reviewer for raising this important point.

We first clarify that the mass enhancement reported in our work is not extracted from kink features in the dispersion, which are typically associated with electron–phonon coupling. Instead, it is determined from the slope of the dispersion in the immediate vicinity of the Fermi level, where the bands remain approximately linear. In our data, deviations from linearity appear at higher binding energies and may be associated with electron–phonon interactions. For example, for the q_1 branch, we obtain mass enhancement factors of $\frac{m_1^*}{m_1^{DFT}} = (1.23, 1.19, 1.40)$, based on the near- E_F slopes. Following Reviewer #3’s suggestion, the values have been slightly updated in the revised analysis to $(1.33, 1.19, 1.47)$. In this updated analysis, the dispersions are extracted from Feenstra-normalized conductance maps, defined as $L(r, E) \equiv \frac{dI/dV(r, E)}{I/V(r, E)}$, to reduce possible set-point effects [Feenstra, R. M. *et al. Surface Science* **181**, 295–306 (1987); Hanaguri, T. *et al. Sci. Adv.* **4**, eaar6419 (2018); Kostin, A. *et al. Nat. Mater.* **17**, 869–874 (2018)]. In addition, we no longer subtract the Gaussian background of the low-frequency signals during the analysis.

In contrast, Ref. 32 extracts electron–phonon coupling strength ($1 + \lambda = 1.4 \sim 1.6$) from kink features located at ~ -32 meV below the Fermi level by comparing the dispersion to a “bare” band defined over a broader energy range. Because our analysis is restricted to the low-energy regime near E_F , away from the kink energy scale, a smaller and smoother renormalization is expected. Therefore, the two quantities are not directly comparable, as they probe different energy ranges and aspects of the quasiparticle self-energy.

In addition, a direct comparison is further complicated by differences in sample composition. Ref. 32 reports results on Nb-doped samples, $(\text{Cs}(\text{V}_{0.93}\text{Nb}_{0.07})_3\text{Sb}_5)$, where the electron–phonon coupling strength shows band- and orbital-dependent variations. This suggests that doping can significantly modify the coupling strength, and similar effects may be present in Ti-doped CsV_3Sb_5 .

Finally, we emphasize that our primary focus is on the symmetry breaking of low-energy quasiparticles near the Fermi surface, rather than on a detailed characterization of electron–phonon coupling. A comprehensive investigation of electron–phonon effects in Ti-doped CsV_3Sb_5 is beyond the scope of the present work and remains an interesting direction for future studies.

We have clarified in the revised manuscript to better distinguish the difference.

“...The deviations from the linear behavior sufficiently above and below the Fermi level are due to the electron-phonon coupling that produces the “kink” feature observed in the quasiparticle dispersion^{30,32}. Here, we focus only on the low-energy velocities extracted away from these kink features. Remarkably, the velocities of the scattering dispersion $v_{1,s}^m$ are different in all three $A - H_m$ directions...”

In summary, we believe we have addressed all comments and questions raised by the Reviewer, adding new data and discussions. Once again, we sincerely thank the Reviewer for the insightful, and constructive comments, which have helped us to further strengthen the manuscript.

Response to the Reviewer #3

Referee Report – “The ‘parent’ state in kagome metals and superconductors: Chiral-nematic Fermi liquid state”

The study of correlated and topological phases in kagome metals has attracted substantial attention in condensed matter physics, both experimentally and theoretically. In this context, the work by Huang et al. is timely and potentially significant. The proposal of a chiral-nematic Fermi liquid as a parent state is particularly interesting, as it suggests a hierarchical mechanism leading to chiral superconductivity, rather than a scenario governed by multiple competing orders

Experimentally, the authors employ scanning tunneling microscopy and spectroscopy, including quasiparticle interference (QPI) measurements, on Ti-doped $\text{CsV}_3\text{--}x\text{Ti}_x\text{Sb}_5$. For $x = 0.15$, no charge density wave (CDW) order is observed, and Fourier-transformed QPI patterns indicate broken mirror symmetries. The comparison between different surface regions suggests the presence of at least two chiral domains. Furthermore, tunneling spectra at 0.4 K exhibit a U-shaped superconducting gap in the spatially averaged local density of states. For $x = 0.05$, similar symmetry reduction is observed alongside diffraction signatures of CDW order.

The experimental effort is substantial and commendable. The systematic characterization across doping levels and temperatures is necessary to support the central claim that a chiral-nematic Fermi liquid underlies both the CDW and superconducting phases.

However, in its current form, the manuscript requires significant clarification and additional analysis before it can be considered for publication.

Response: We sincerely thank the Reviewer for the summary and for the positive assessment of our work as “timely” and “potentially significant.” We particularly appreciate the Reviewer’s recognition that the identification of the parent chiral-nematic Fermi liquid is “particularly interesting” and that the experimental effort is “substantial and commendable.” We also thank the Reviewer for the valuable comments and constructive suggestions, which we address point by point below.

Comment 1: *Surface preparation and its impact on electronic structure. The authors state that Cs atoms are removed by the STM tip to obtain a clean Sb surface. While this may facilitate QPI measurements, it raises a critical concern: how does the removal of Cs atoms—present in the bulk—affect the surface electronic structure and symmetry? Could this procedure itself induce symmetry breaking or modify the observed QPI patterns? This issue must be addressed quantitatively or, at minimum, discussed in detail.*

Response 1: We thank the Reviewer for raising this important concern. To address the possible impact of the Cs-removal procedure on the electronic structure, we performed additional QPI measurements directly on the naturally cleaved Cs-terminated surface, where no STM manipulation or Cs removal was applied. The corresponding results are presented in the newly added Fig. S14.

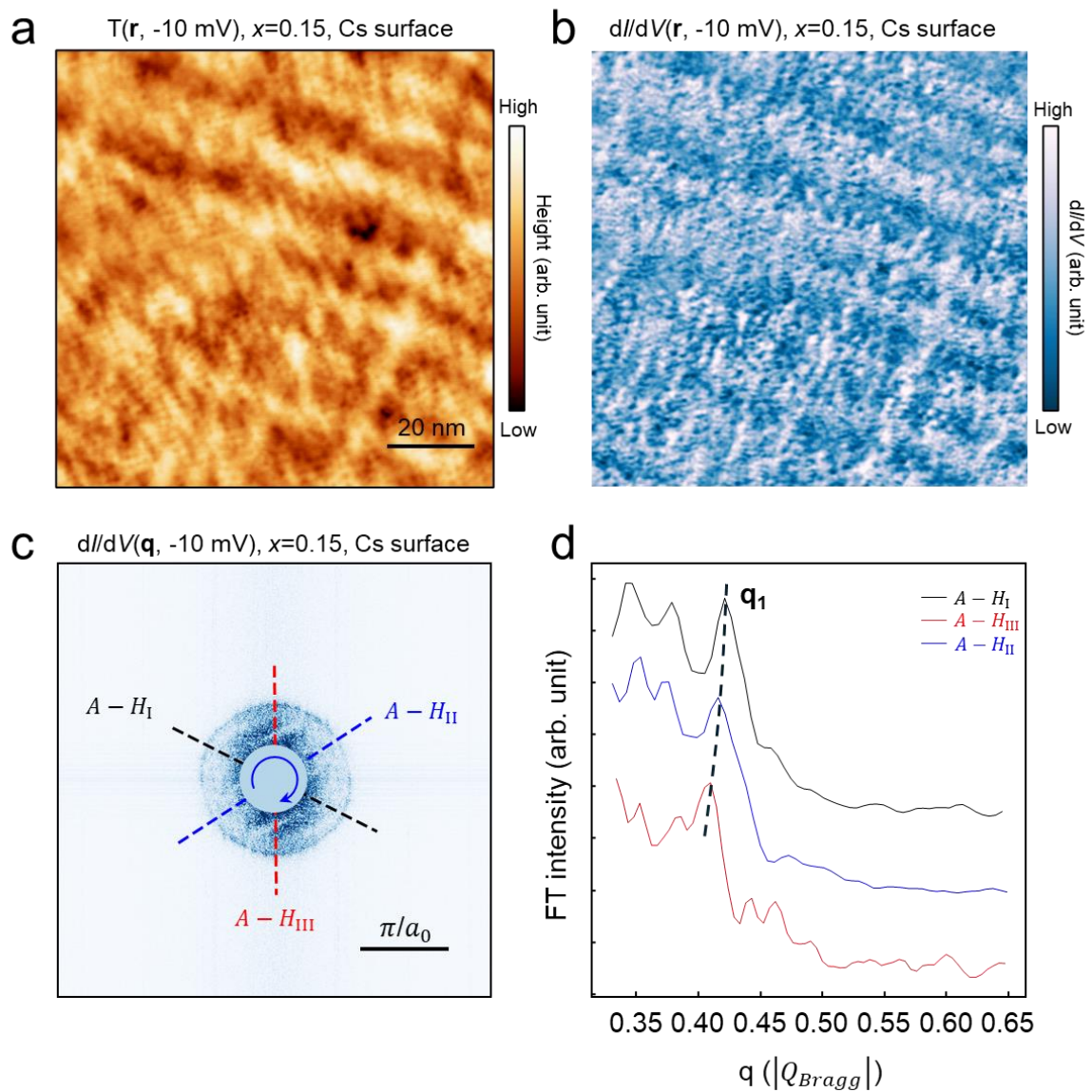
Figure S14a shows the pristine Cs-terminated surface immediately after cleaving. The corresponding dI/dV map (Fig. S14b) exhibits real-space QPI modulations. Fourier transformation of the data reveals the dominant q_1 scattering feature (Fig. S14c), which displays anisotropy along the $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions. This anisotropy becomes more evident in the line profiles extracted along the three directions (Fig. S14d), where the q_1 scattering vectors exhibit different peak positions.

These observations support that the rotational and mirror symmetry breaking in the electronic structure

can also be observed on the pristine Cs-terminated surface without any Cs-removal procedure. Therefore, the observed chiral-nematic QPI features are unlikely to originate from the surface preparation process itself, and instead reflect an intrinsic property of the electronic structure.

We have added a new Supplementary Information Section E to discuss the rotational- and mirror-symmetry-breaking QPI of Cs surface and referred Fig. S14 in the main text.

“...low concentration at $x = 0.05$ (Fig. 4), intermediate at $x = 0.15$ (Fig. 2, Supplementary Figs. S3 and S4), and high concentration at $x = 0.27$ (Supplementary Fig. S5). **In addition, chiral QPI has also been observed on the Cs-terminated surface (Fig. S14).** This suggests that the rotation and mirror symmetry breaking is present independent of the Ti doping level **and surface termination.**”



New Fig. S14. Rotational and mirror symmetry breaking on the Cs surface. **a**, STM topography of the Cs surface. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern. **c**, FT of (b), showing asymmetric q_1 along different directions. **d**, Line profiles extracted from (c) along the dotted lines for the $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions, respectively, revealing different length of the q_1 , which indicate the chirality of $q_1^{H_m}$ ($i = 1, 2, 3; m = I, II, III$). The different lengths of q_1 are guided by dotted curves.

Comment 2: *Crystal symmetry and notation. The symmetry description is ambiguous. The space group $P6/mmm$ (line 78) implies C_6 symmetry, whereas later (line 103) the symmetry is described as “ C_3 plus inversion.” Are these statements referring to bulk versus surface symmetry? Do the C_3 axis and inversion center coincide spatially? The precise symmetry group relevant for the QPI analysis should be clearly stated.*

Response 2: We thank the Reviewer for raising this important point. The two symmetry descriptions are not contradictory, but instead refer to different aspects of the system. The “ C_3 plus inversion” symmetry mentioned in the manuscript refers specifically to the symmetry of the QPI patterns in the Fourier-transformed q -space.

The crystal lattice of CsV_3Sb_5 belongs to the space group $P6/mmm$, which possesses sixfold rotational (C_6) symmetry in real space. This describes the symmetry of the bulk crystal structure, where the C_6 axis, C_3 axis, and inversion center spatially coincide. At the surface, the combination of threefold rotational symmetry and inversion symmetry can produce an effective sixfold-symmetric QPI intensity pattern because the rotational center and inversion center coincide.

However, in the manuscript we use the term “ C_3 plus inversion” to emphasize that the inversion symmetry observed in the QPI maps is intrinsically preserved by the Fourier transformation itself, rather than representing an independent rotational symmetry operation. Specifically, for Fourier-transformed STM conductance maps, inversion symmetry is intrinsically preserved because the real-space conductance modulation $f(\mathbf{r})$ is a real-valued function. Its Fourier transform satisfies

$$F(\mathbf{q}) = \int_{-\infty}^{\infty} f(\mathbf{r}) e^{-i\mathbf{q}\cdot\mathbf{r}} d\mathbf{r},$$

which leads to the relation

$$F(-\mathbf{q}) = F^*(\mathbf{q}),$$

and therefore the Fourier intensity satisfies

$$|F(-\mathbf{q})| = |F(\mathbf{q})|.$$

As a result, the QPI intensity pattern always exhibits inversion symmetry in q -space. Consequently, a threefold rotationally symmetric scattering pattern naturally appears as an effective sixfold-symmetric intensity distribution in the Fourier-transformed QPI maps.

To avoid ambiguity, we revise the “ C_3 plus inversion” description to:

“Apparent QPI C_6 symmetry arising from C_3 symmetry combined with the intrinsic inversion symmetry of Fourier-space intensity maps”.

Comment 3: *Reliability of QPI intensity analysis (Fig. 1d – g, 1e, 1g). Comparing Fig. 1e and 1g, electronic-structure-related features appear with inverted intensity (e.g., $A - \text{HI}$ high in g but low in e). How are set-point effects and topographic contributions removed in the Fourier-transformed dI/dV data? Is the observed asymmetry intrinsic or an artifact of measurement conditions? This requires explicit clarification.*

Response 3: We thank the Reviewer for this important question. The intensity differences between Fig. 1e and Fig. 1g originate from the fact that these two Fourier-transformed images correspond to fundamentally different physical quantities.

Specifically, Fig. 1e shows the Fourier transform of the topographic image $z(\mathbf{r})$ in Fig. 1d, whereas Fig. 1g shows the Fourier transform of the dI/dV conductance map in Fig. 1f. In constant-current STM mode, the topographic signal is related to the tunneling current through

$$I \propto e^{-\kappa z},$$

where κ is the tunneling decay constant associated with the work function. Consequently,

$$z(\mathbf{r}) \propto -\frac{1}{\kappa} \ln I,$$

and therefore reflects the energy-integrated local density of states within the bias window, rather than the differential conductance at a single energy. As a result, there is no requirement that the Fourier intensities in Fig. 1e and Fig. 1g exhibit the same contrast or relative peak intensities.

To further verify that the observed rotational and mirror symmetry breaking in the QPI patterns is intrinsic rather than arising from set-point effects or topographic artifacts, we additionally analyzed the Feenstra-normalized conductance maps (newly added Fig. S15), defined as

$$L(\mathbf{r}, E) \equiv \frac{dI/dV(\mathbf{r}, E)}{I/V(\mathbf{r}, E)} = \frac{eV}{\int_0^{eV} n(\mathbf{r}, \epsilon) d\epsilon} n(\mathbf{r}, E),$$

which is widely used to suppress possible set-point effects in STM measurements [Feenstra, R. M. et al. Surf. Sci. 181, 295–306 (1987); Hanaguri, T. et al. Sci. Adv. 4, eaar6419 (2018); Kostin, A. et al. Nat. Mater. 17, 869–874 (2018)].

The Fourier-transformed normalized conductance map (Fig. S15b), obtained from $L(\mathbf{r}, E)$ (Fig. S15a), exhibits the same rotational- and mirror-symmetry breaking observed in the original QPI data. In particular, the line profiles (Fig. S15c) extracted along the $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions still show distinct q_1 , q_2 , and q_3 scattering vectors with different lengths, demonstrating that the anisotropy remains robust after normalization.

In addition, we have applied the same Feenstra normalization procedure to the conductance maps used for the QPI dispersion analysis in Fig. 3 (also related to the response to Comment 7). Although the extracted Fermi velocities and renormalized mass ratios near the Fermi level are slightly updated, the observed chirality and symmetry-breaking behavior remain robust. These results further support that the observed asymmetry is intrinsic rather than an artifact arising from measurement conditions or set-point effects.

We have now updated the normalized conductance map in Fig. 3 and the extracted values in the revised manuscript. We have also added a discussion on the removal of set-point effects in the Method.

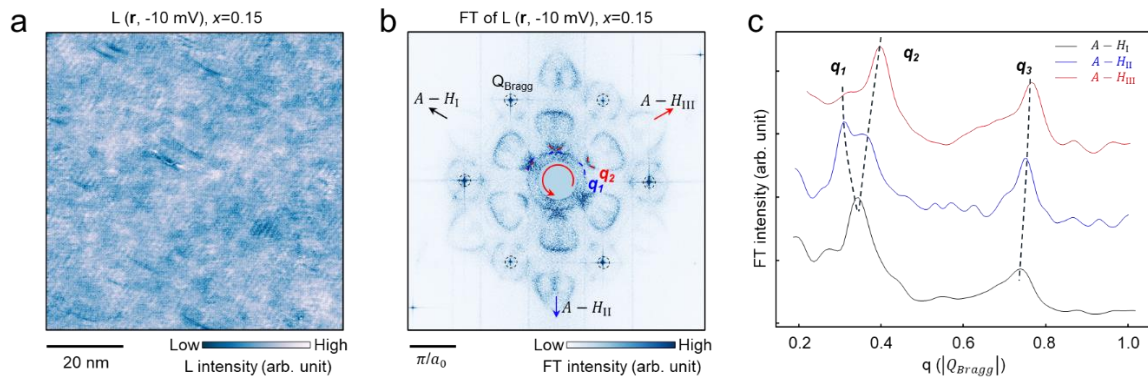
“...The line profiles in the Fourier transforms of the **Feenstra-normalized conductance maps** $L(\mathbf{r}, E) \equiv \frac{dI/dV(\mathbf{r}, E)}{I/V(\mathbf{r}, E)}$ (see **Methods**) are shown in Fig. 3a along cut #1 (Fig. 2b)...”

“Removal of set-point effect. The Feenstra-normalized conductance maps (Fig. S15), defined as

$$L(\mathbf{r}, E) \equiv \frac{dI/dV(\mathbf{r}, E)}{I/V(\mathbf{r}, E)} = \frac{eV}{\int_0^{eV} n(\mathbf{r}, \epsilon) d\epsilon} n(\mathbf{r}, E),$$

is widely used to suppress possible set-point effects in STM measurements^{43–45}. An example is shown in Fig. S15. This treatment renders $L(r, eV)$ independent of set-point condition, thereby enabling a

consistent comparison of results obtained from different samples and with varying setpoints.”



New Fig. S15. Rotational and mirror symmetry breaking using Feenstra-normalized conductance map. **a**, Feenstra normalized conductance map of the data in Fig. 1f. **b**, FT of (a), showing rotational and mirror symmetry breaking QPI pattern. **c**, Line profiles extracted from (b) along the $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions, respectively, revealing different length of the q_1 , q_2 , and q_3 , which indicate the chirality of $q_i^{H_m}$ ($i = 1, 2, 3; m = I, II, III$). The different lengths of q_1 , q_2 , and q_3 are guided by dotted curves.

Comment 4: *Affine transformation and Bragg peak alignment (Fig. 1e, 1g). An affine transformation (presumably a Lawler – Fujita correction) is applied to align Bragg spots. The exact procedure should be specified. How are genuine lattice distortions or physical inequivalence of Bragg vectors excluded? How is the remaining intensity difference between corrected Bragg peaks explained?*

Response 4: We thank the Reviewer for this important comment. We clarify that the affine transformation procedure, rather than a full Lawler–Fujita drift-correction method, was applied only to Figs. 2b and 4d, as stated in the new Supplementary Information Section B. Such procedures are commonly used in STM studies to remove instrumental drift and scanning nonlinearity [Gu, Q. *et al. Nature* **618**, 921–927 (2023)]. In the present work, the correction is used only for visualization purposes and to facilitate symmetry comparison of the electronic structure, rather than the lattice structure itself.

Importantly, this affine transformation was not applied to the quantitative analyses used in this work, including the extraction of QPI line profiles, scattering vectors, or dispersions. Therefore, the correction procedure does not affect the quantitative results or the conclusions regarding the observed electronic symmetry breaking.

To directly address the Reviewer’s concern regarding possible intrinsic lattice distortions or inequivalent Bragg vectors, we analyze the lattice symmetry directly from the raw (uncorrected) data, as shown in a new Fig. S12. We compare the three Bragg vectors Q_A , Q_B , and Q_C from the Fourier-transformed topography (Fig. S12a), and show their line profiles (Fig. S12b). Gaussian fitting of the peak positions (Fig. S12c) yields variations in the Bragg vector magnitudes of less than $\sim 1\%$ relative to their average value. Considering the full width at half maximum as an estimate of uncertainty, these differences fall within the error bars, indicating that any deviation from ideal lattice symmetry is negligible. The standard error of the extracted peak positions is $\sim 0.5\%$.

In contrast, the anisotropy observed in the QPI wave vectors is significantly larger. For example, the variation in q_2 reaches up to $\sim 3\%$ near the Fermi level, exceeding the uncertainty associated with

Bragg peak analysis. This suggests that the observed mirror and rotational symmetry breaking is primarily reflected in the electronic structure.

Regarding the remaining intensity differences between the corrected Bragg peaks, we emphasize that the symmetry breaking discussed in the present work is determined primarily from the momentum positions of the QPI scattering vectors rather than from the Bragg peak intensities themselves. Small residual intensity variations of the Bragg peaks can naturally arise from such as tunneling matrix-element effects, finite field-of-view effects, local disorder, and residual experimental noise, and therefore do not imply intrinsic inequivalence of the lattice vectors.

We have now added a detailed description of the affine procedure and new analysis in the Supplementary Information (Section B):

“Using the three Bragg peaks as reciprocal lattice basis vectors, a global linear transformation matrix A was constructed such that the transformed Bragg vectors satisfy $|A\mathbf{Q}_A| = |A\mathbf{Q}_B| = |A\mathbf{Q}_C|$, and are separated by 60 degrees.

After correction, the reciprocal lattice forms an ideal hexagonal geometry. Since the same linear transformation acts uniformly on all momentum vectors, the relative momentum-space structure and intrinsic QPI topology are preserved.”

“We further analyze the lattice symmetry directly from the raw (uncorrected) data, as shown in a Fig. S12. We compare the three Bragg vectors $\mathbf{Q}_A$, $\mathbf{Q}_B$, and $\mathbf{Q}_C$ from the Fourier-transformed topography (Fig. S12a), and show their line profiles (Fig. S12b). Gaussian fitting of the peak positions (Fig. S12c) yields variations in the Bragg vector magnitudes of less than $\sim 1\%$ relative to their average value. Considering the full width at half maximum as an estimate of uncertainty, these differences fall within the error bars, indicating that any deviation from ideal lattice symmetry is negligible. The standard error of the extracted peak positions is $\sim 0.5\%$.

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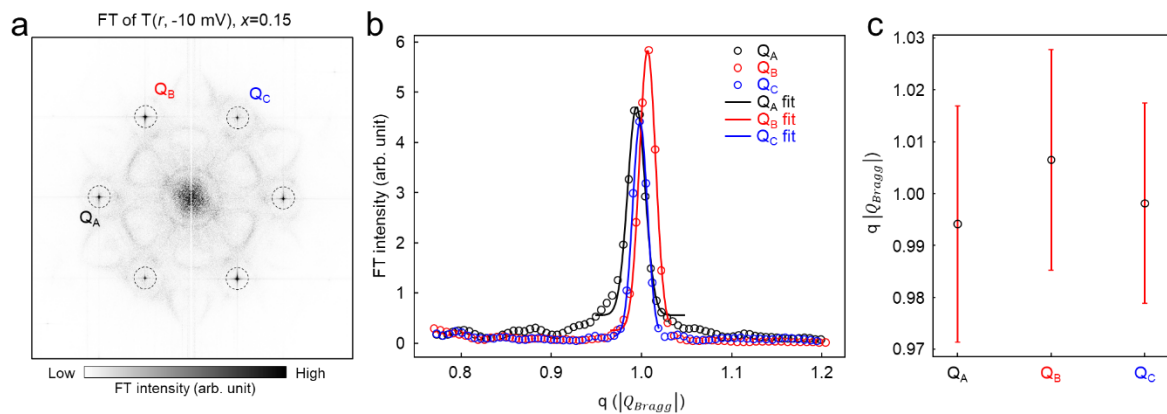


Fig. S12. Lattice structure symmetry analysis. **a**, Fourier-transformed topography (same as Fig. 1e), showing the Bragg peaks $\mathbf{Q}_A$, $\mathbf{Q}_B$, and $\mathbf{Q}_C$. **b**, Lengths of the Bragg vectors $\mathbf{Q}_A$, $\mathbf{Q}_B$, and $\mathbf{Q}_C$. The peaks are fitted with Gaussian function. The unit of the length represents their average value. **c**, Extracted lengths of $\mathbf{Q}_A$, $\mathbf{Q}_B$, and $\mathbf{Q}_C$. Error bars represent the full width at the half maximum (FWHM) of the fitted Gaussian peaks.

Comment 5: *Relation between Fig. 1g and Fig. 2. It is unclear whether Fig. 2 is derived from the same dataset as Fig. 1g. If so, this should be explicitly stated; if not, differences in acquisition conditions should be clarified.*

Response 5: We thank the Reviewer for raising this point and apologize for the lack of clarity. Figure 2a is derived from the same dataset as Fig. 1g and corresponds to a three-dimensional zoom-in visualization of the Fourier-transformed QPI map shown in Fig. 1g. No additional measurements or different acquisition conditions were involved.

To avoid confusion, we have now explicitly clarified this point in the figure caption.

“a, 3D plot of the zoomed-in FT of the dI/dV map in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) with the same dataset as Fig. 1g, highlighting the QPI patterns.”

Comment 6: *Signal-to-noise and robustness of symmetry breaking (Fig. 2b – d, 2g). Since Fig. 2 illustrates the central experimental claim, a quantitative estimate of the signal-to-noise level is required. In panel 2g, an additional ring-like feature slightly shorter than q_1 appears in the central region—this should be addressed (artifact vs. physical signal). Are the line profiles shown in panels 2c and 2d raw data or averaged? If averaging is performed, the procedure should be specified. Furthermore, why is the analysis consistently shown at ~ 10 mV (or 5 mV in the SI)? Is the observed symmetry breaking strongly bias-dependent? In panel 2b, the use of grey dashed lines is confusing and should be clarified.*

Response 6: We thank the Reviewer for these important comments regarding the robustness of the observed symmetry breaking.

To estimate the signal-to-noise ratio of the QPI features, we compare the average peak intensity of the q_1 , q_2 , and q_3 scattering vectors with the average background intensity in the Fourier-transformed conductance map. The average peak intensity is approximately 3.08×10^{-9} a.u., while the average background noise level is approximately 2.28×10^{-10} a.u., yielding an estimated signal-to-noise ratio of ~ 13.5 . These values indicate that the observed anisotropic QPI features are well above the background noise level. Furthermore, we would like to emphasize that the observed symmetry breaking is robust, as it is consistently observed across multiple energies (Fig. 3) and samples (see additional datasets in Supplementary Information).

Regarding the additional ring-like feature appearing slightly inside the q_1 contour in Fig. 2g, we clarify that this feature does not correspond to a physical closed scattering ring. Instead, it mainly originates from the low-frequency region of the Fourier-transformed dI/dV map, which contains long-wavelength background contributions. The apparent ring-like shape arises because a circular mask was applied to mask the central low-frequency intensity for clearer visualization of the QPI features of interest. We now provide the corresponding unmasked raw Fourier-transformed data in the Response Fig. R4 for clarification.

Interestingly, our QPI simulations in Fig. 2f suggest that an additional inner scattering feature may in principle exist inside the q_1 contour, originating from inter-pocket scattering associated with the triangular in-plane d -orbital-derived pockets. However, in the experimental data this possible feature lies very close to the low-frequency background region in q -space, making it difficult to distinguish unambiguously from low-frequency background contributions.

The line profiles shown in Figs. 2c and 2d are not single-pixel traces. Instead, they are obtained by

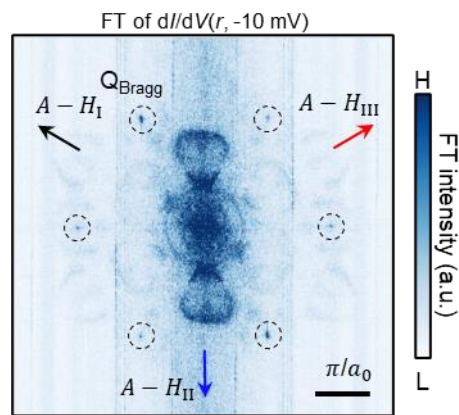
averaging over six neighboring pixel lines along the corresponding symmetry directions, as stated in the Methods section, in order to improve the signal-to-noise ratio.

We mainly discuss the low-bias (~ 10 mV and ~ 5 mV) data because the observed symmetry breaking is strongly energy dependent. As shown in the dispersions in Figs. 3a and 3c, the differences among q_1 , q_2 , and q_3 become most pronounced in the low-energy regime near the Fermi level, indicating that the symmetry breaking is closely associated with low-energy correlated quasiparticles.

Finally, in Fig. 2b, the grey dashed lines are included only as visual guides to facilitate comparison of the q_2 scattering vectors along the three symmetry-related directions. We have clarified this point in the revised figure caption.

“The grey dashed lines are included as visual guides to facilitate comparison of the q_2 scattering vectors.”

We have now discussed the signal-to-noise and low-frequency signals in a new Supplementary Information Section F.



Response Fig. R4. Fourier-transformed $dI/dV(r, -10$ meV) data corresponding to Fig. 2g without the central mask applied. The central block region contains the low-frequency components of the map.

Comment 7: QPI fitting procedure and dispersion analysis (Fig. 3c, 3d, Fig. S2). The fitting methodology lacks transparency. What are the “Gaussian-like backgrounds” that are subtracted, and why do they vary with bias voltage? The Lorentzian fits shown in Fig. S2 appear ambiguous; quantitative measures of fit quality should be provided. Are the line profiles averaged in momentum space? In panels 3c and 3d, linear dispersions are fitted to extract Fermi velocities. The comparison with DFT (lines 185 – 194) highlights directional dependence in experiment that is absent in theory—how would this comparison change when including the proposed Pomeranchuk distortion (line 142)? Deviations from linear dispersion are attributed to electron – phonon coupling: which phonon mode is responsible, and is there a corresponding suppression in QPI intensity?

Response 7: We thank the Reviewer for these important comments regarding the QPI fitting procedure and dispersion analysis.

The low-frequency region near the center of the Fourier-transformed conductance maps generally contains strong long-wavelength background contributions originating from slowly varying spatial inhomogeneity, possible residual set-point effects, and non-QPI components of the STM signal. In the

original analysis, this background was modeled and removed using a Gaussian function, a procedure commonly used in QPI analysis to improve visualization of finite- q scattering features [Allan, M. P. *et al. Science* **336**, 563–567 (2012); Chi, S. *et al. Phys. Rev. B* **89**, (2014)]. The apparent bias dependence of this background mainly reflects variations in the overall conductance intensity and tunneling conditions at different energies.

To address the Reviewer’s concern more rigorously, we have now reanalyzed the data using Feenstra-normalized conductance maps (see also Response 3),

$$L(\mathbf{r}, E) \equiv \frac{dI/dV(\mathbf{r}, E)}{I/V(\mathbf{r}, E)},$$

without subtracting the Gaussian background. The updated results are presented in the revised Fig. 3a and revised Figs. 3c–d. The extracted dispersions, Fermi velocities, and mass renormalization factors are slightly modified compared to the original analysis, but the observed symmetry-breaking anisotropy and chirality remain robust, further confirming that the conclusions do not depend on the background-subtraction procedure.

Regarding the Lorentzian fitting shown in Fig. S2, we have revised the supplementary figure with adjusted intensity scales to better visualize the fitting quality. The extracted QPI peak positions are obtained from Lorentzian fits to the momentum-space line profiles. The quality of the fits is demonstrated by the close agreement between the fitted curves and the experimental data, as well as by the relatively small fitting uncertainties shown as error bars in Figs. 3c–d. In addition, the line profiles are not single-pixel traces; instead, they are obtained by averaging over six neighboring momentum-space lines along the corresponding symmetry direction, as stated in the Methods section, in order to improve the signal-to-noise ratio.

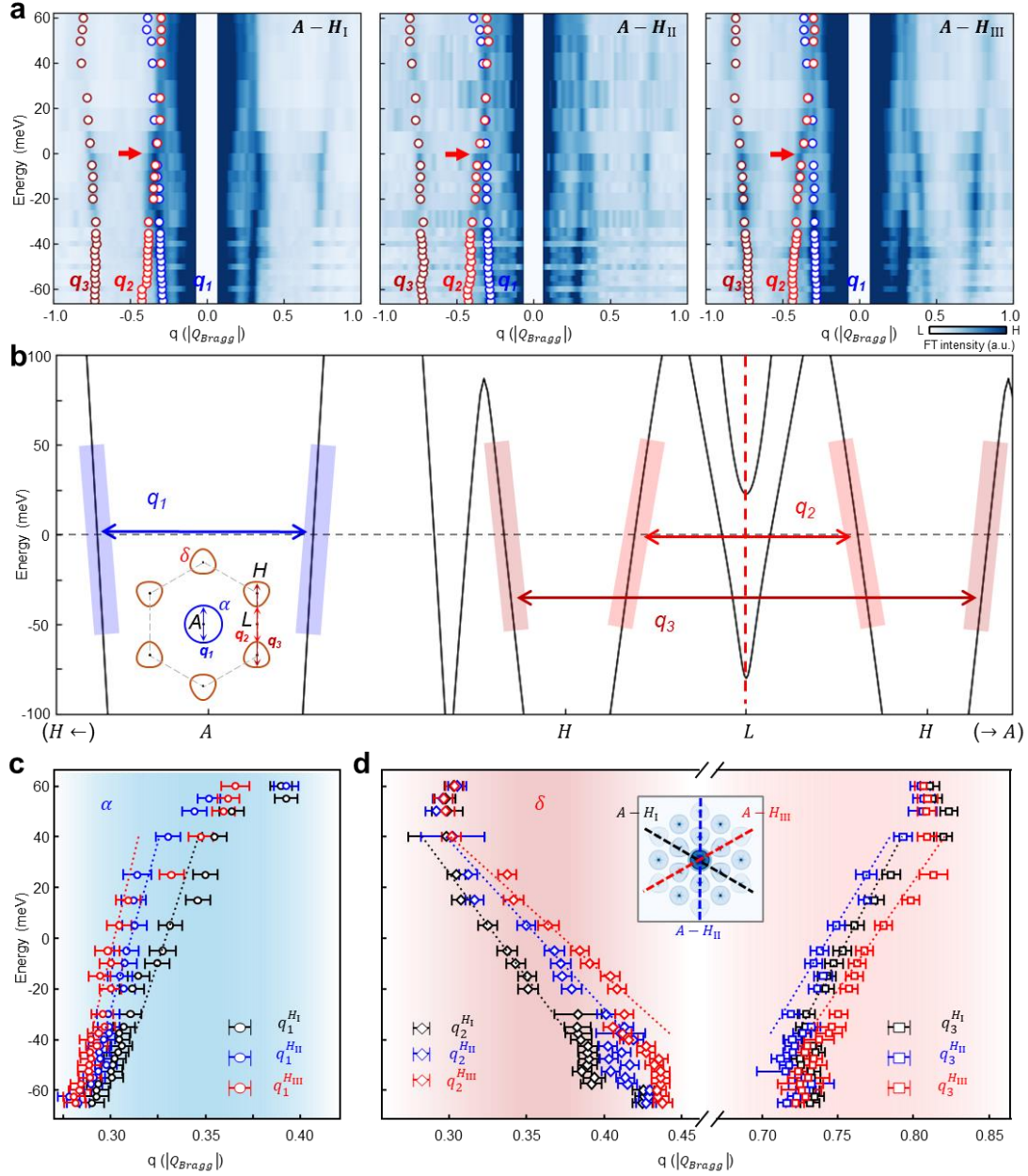
For the comparison with DFT, the calculated dispersions preserve the threefold rotational symmetry along the three A–H directions, whereas the experimental QPI dispersions exhibit clear directional anisotropy. We propose that this discrepancy can be naturally understood in terms of a d -wave Pomeranchuk distortion, which breaks the rotational symmetry of the Fermi surface. Since the QPI dispersions are directly determined from the evolution of the constant-energy contours with energy, a symmetry-breaking deformation of the Fermi surface naturally leads to anisotropic q -space dispersions.

To illustrate this effect, in Figs. 2e–f we introduce a phenomenological d -wave Pomeranchuk distortion into the calculated Fermi surface at Fermi level. The resulting simulated QPI patterns reproduce the experimentally observed anisotropic scattering vectors remarkably well, supporting the interpretation that the observed directional dependence originates from a Pomeranchuk-like instability.

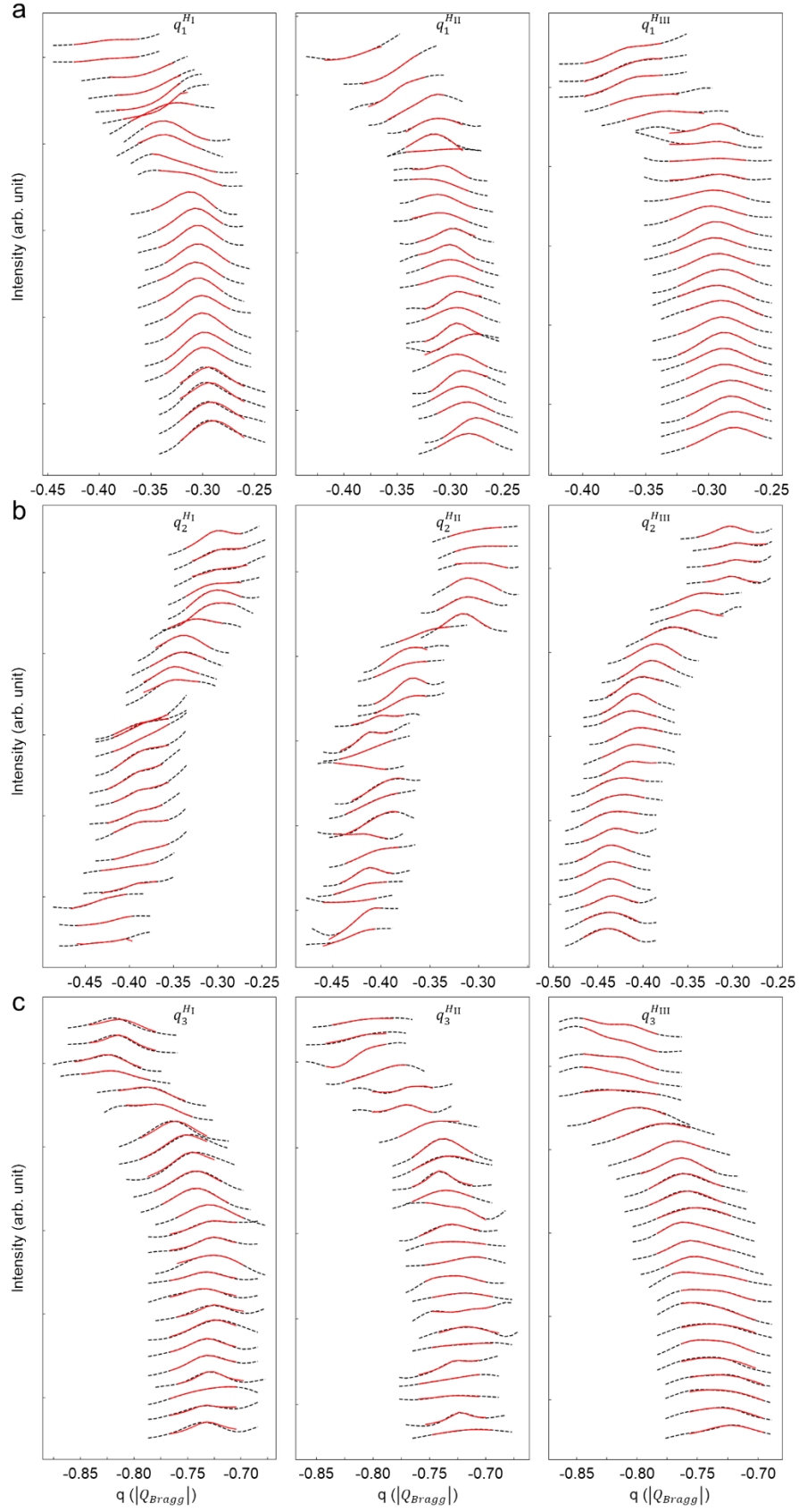
At the same time, we emphasize that the present phenomenological simulation is intended to capture the symmetry-breaking behavior qualitatively rather than to provide a fully self-consistent many-body calculation. Incorporating such correlation-driven symmetry breaking directly into first-principles calculations is beyond the scope of the present work and would require future theoretical investigation.

Regarding the deviations from linear dispersion below the Fermi level, we attribute the observed kink-like features to electron–phonon coupling, consistent with Ref. 32 [Zhong, Y. *et al. Nat. Commun.* **14**, 1945 (2023)], which reported kink structures at approximately -32 meV in CsV₃Sb₅. In our measurements, the electron–phonon coupling manifests primarily as a change in the quasiparticle dispersion slope arising from self-energy renormalization, rather than as a strong suppression of the QPI intensity itself. At present, our data do not allow us to unambiguously identify a specific phonon mode responsible for the renormalization. A detailed investigation of electron–phonon coupling in Ti-doped CsV₃Sb₅ is beyond the scope of the present work and remains an interesting direction for future studies.

We have added a new Supplementary Information Section D describing the fitting procedure in detail.



Revised Fig. 3. Observation of chiral-nematic quasiparticle dispersions and renormalizations in Ti-doped CsV_3Sb_5 without CDW order. **a**, Bias-dependent QPI line profiles extracted from the FTs of Feenstra-normalized conductance maps $L(\mathbf{r}, E)$ along the $A - H_I$ (left), $A - H_{II}$ (middle), and $A - H_{III}$ (right) directions (cut#1), respectively, showing the dispersions of q_1 , q_2 , and q_3 . The colored open circles highlight the quantitative values of q_1 , q_2 , and q_3 extracted from QPI line profiles. The red arrows highlight the difference around the Fermi level. Center low-frequency backgrounds are masked for better view. **b**, DFT-calculated electronic structure at $k_z = \pi$, showing the bands from which the q_1 , q_2 , and q_3 originate, as marked by arrowed lines in blue and red. Inset is the corresponding Fermi surface with q -vectors indicated. **c**, **d**, Dispersions $E_s(q_1)$ (**c**), $E_s(q_2)$, and $E_s(q_3)$ (**d**) extracted from (**a**) along $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions, respectively, showing the chiral Fermi velocity renormalizations at low energy. Dotted lines show the linear fittings of the dispersions at low energy.



Revised Fig. S2. Lorentzian fitting of the q -dispersions. **a-c**, Lorentz fitting (red curves) for q_1 (**a**), q_2 (**b**), and q_3 (**c**) along $A - H_I$ (left), $A - H_{II}$ (middle), and $A - H_{III}$ (right) directions. Black dotted curves are raw data.

Comment 8: *Consistency between $x = 0.15$ and $x = 0.05$ (Fig. 4e). In Fig. 4, the identification of q_1 , q_2 , and q_3 becomes difficult. In the line cut shown in panel 4e (is this averaged?), q_3 falls below the noise level in two out of three curves, q_1 shows little variation, and the shift of q_2 differs noticeably from Fig. 2c. Given these discrepancies, in what sense do both doping levels exhibit the same chiral-nematic Fermi surface?*

Response 8: We thank the Reviewer for this important comment. We would first like to emphasize that the identification of the chiral-nematic Fermi liquid state in our work is based primarily on the symmetry properties of the low-energy QPI patterns, namely the simultaneous breaking of rotational and mirror symmetries in momentum space, rather than on the absolute intensity of individual scattering vectors.

In the QPI measurements, this symmetry breaking manifests as directional dependence of the scattering-vector positions along the three symmetry-related directions. Therefore, the key criterion is whether the anisotropic momentum-space structure persists, rather than whether the QPI intensity remains equally strong for all scattering channels.

We agree that the QPI patterns in the $x = 0.05$ sample differ noticeably from those in the $x = 0.15$ sample. In particular, the lower-doped sample additionally exhibits 2×2 CDW vectors, 4×1 charge modulation vectors, and unidirectional stripe-like QPI features. Moreover, the triangular QPI features associated with the in-plane d -orbital-derived pockets (q_2 and q_3) become significantly weaker in the $x = 0.05$ sample. This weakening is likely related to partial gapping of the low-energy electronic states by the coexisting CDW order.

Nevertheless, despite the reduced intensity, the same rotational- and mirror-symmetry breaking can still be identified in the $x = 0.05$ sample. First, this is qualitatively visible in Figs. 4d and 4e through the directional-dependent separation between the q_1 and q_2 scattering vectors, as well as the asymmetric distortion and directional tilt of the triangular q_3 feature. Second, the line profiles in Fig. 4e (which are averaged over six neighboring pixels, as stated in the Methods section) show clear momentum shifts of the scattering vectors (especially q_2) along different symmetry directions. Although the variation of q_1 is relatively small and the q_3 feature becomes weak, the anisotropic separation among the scattering vectors q_1 and q_2 remains distinctive.

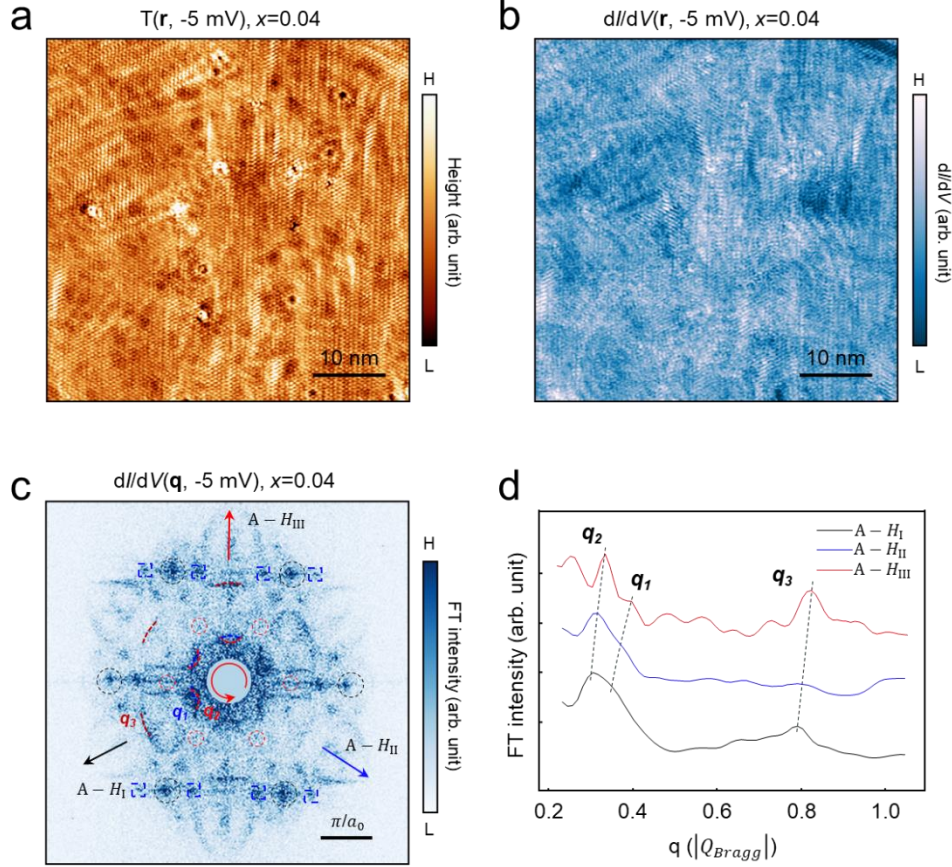
Therefore, while the detailed spectral weight distribution evolves significantly with doping and coexisting CDW order, the underlying symmetry-breaking behavior of the low-energy electronic structure remains qualitatively consistent between the two doping levels. In this sense, both samples exhibit the same chiral-nematic Fermi liquid state.

Furthermore, to demonstrate the robustness of the rotational- and mirror-symmetry breaking in lightly Ti-doped CsV_3Sb_5 in the presence of CDW order, we additionally measured an $x = 0.04$ sample, shown in the newly added Fig. S16. As shown in Figs. S16a–c, the 2×2 CDW order, 4×1 charge modulation, and unidirectional stripe-like QPI features remain present. Despite these additional ordered states, the momentum-space line profiles (Fig. S16d) still exhibit clear directional dependence of the scattering-vector positions, indicating persistent rotational- and mirror-symmetry breaking. This additional dataset further supports the robustness of the chiral-nematic Fermi liquid state even in the coexistence regime with CDW order.

We have referred to this new data in the revised manuscript as follows:

“We have consistently observed the chirality of the electronic structure in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ through the

reproducible chiral QPI patterns at different energies and across various Ti doping levels: low concentration at $x = 0.04$ (Fig. S16) and $x = 0.05$ (Fig. 4), intermediate at $x = 0.15$ (Fig. 2, Supplementary Figs. S3 and S4), and high concentration at $x = 0.27$ (Supplementary Fig. S5).”



New Fig. S16. Rotational and mirror symmetries breaking on a $x=0.04$ sample. **a**, STM topography of the Sb surface of CsV_{3-x}Ti_xSb₅ ($x=0.04$), showing the presence of charge orders. $V_{bias} = -5$ mV, $I = 200$ pA, $V_{lock-in} = 0.2$ mV. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern. **c**, FT of (b), showing asymmetric q_1 , q_2 , and q_3 along different directions. **d**, Line profiles extracted from (c) along the dotted lines for the $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions, respectively, revealing different length of the q_1 , q_2 , and q_3 , which indicate the chirality of $q_i^{H_m}$ ($i = 1,2,3; m = I, II, III$). The different lengths of q_1 , q_2 , and q_3 are guided by dotted curves.

Comment 9: Bogoliubov QPI analysis. In lines 291 – 293, the authors discuss QPI of Bogoliubov quasiparticles. To mitigate experimental artifacts due to set-point and spatial modulation effects, such data are often analyzed using $z(r,E) = g(r,+E)/g(r,-E)$ or equivalent symmetrization procedures. Have the authors performed such an analysis? If so, are the symmetry-breaking features robust?

Response 9: We thank the Reviewer for this important question regarding the robustness of the Bogoliubov QPI analysis against possible set-point and spatial modulation effects.

In the original manuscript, Fig. S8 presents the chiral Bogoliubov QPI measured at negative bias (Fig. S8d). Due to the limited measurement time available in the ultra-low-temperature ³He STM system, only one bias polarity was initially measured in detail.

To further address the Reviewer's concern, we have now performed additional Bogoliubov QPI measurements on an independent $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x = 0.15$) sample (sample #3), and the new results are presented in Fig. S17.

We note that the ratio analysis $Z(\mathbf{r}, |E|) \equiv \frac{dI/dV(\mathbf{r}, +E)}{dI/dV(\mathbf{r}, -E)}$ has been used in cuprate superconductors to emphasize electron tunneling particle-hole asymmetry and suppress set-point effects [Kohsaka, Y. *et al. Science* **315**, 1381–1385 (2007)]. However, in the present case the tunneling spectra exhibit an approximately particle-hole symmetric superconducting gap structure (inset of Fig. S17a). Correspondingly, the dI/dV maps measured at positive and negative biases display very similar spatial patterns (Figs. S17b–c). As a result, the corresponding $Z(\mathbf{q}, |E|)$ map strongly suppresses the QPI signal itself and therefore is not optimal for resolving the Bogoliubov QPI features in this material (Fig. S17d).

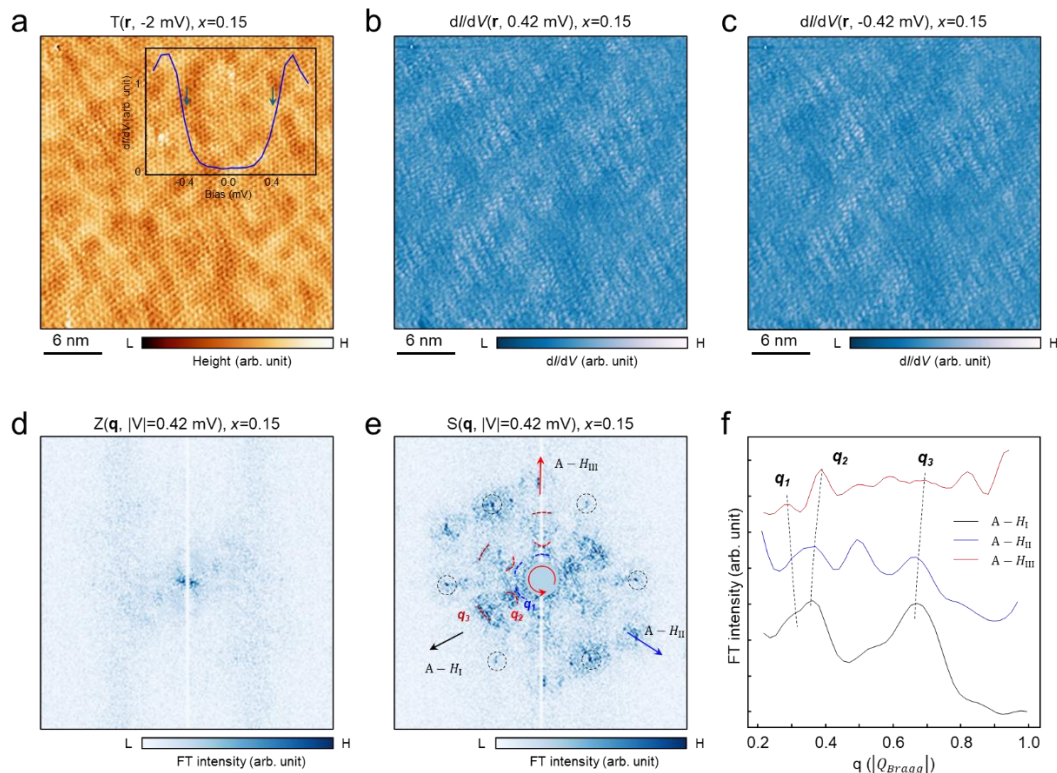
Instead, motivated by previous Bogoliubov QPI studies [Sharma, R. *et al. Proc. Natl. Acad. Sci.* **117**, 5222–5227 (2020)], we performed the analysis using Feenstra-normalized conductance maps, $L(\mathbf{r}, E)$, and constructed the symmetrized map

$$S(\mathbf{r}, |E|) \equiv L(\mathbf{r}, E) + L(\mathbf{r}, -E).$$

The resulting Fourier-transformed $S(\mathbf{q}, |E|)$ map (Fig. S17e) still exhibits clear rotational- and mirror-symmetry breaking, together with distinct scattering vectors $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ of different magnitudes (Fig. S17f). These additional analyses, together with the independent measurements on a second sample, further confirm the robustness of the symmetry-breaking behavior in the Bogoliubov QPI patterns.

We have now clarified these points and added a new Supplementary Information Section G.

“To further test this physical idea, we performed Bogoliubov QPI (B-QPI) measurements in the $x = 0.15$ sample (Supplementary Fig. S8 and Fig. S17)...”



New Fig. S17. Robust rotational and mirror symmetries breaking on Bogoliubov QPI at CsV_{3-x}Ti_xSb₅ (x=0.15) sample #3. **a**, STM topography of the Sb surface of CsV_{3-x}Ti_xSb₅ (x=0.15) sample #3. $V_{bias} = -2$ mV, $I = 200$ pA, $V_{lock-in} = 0.1$ mV. The inset shows the superconducting gap spectrum. **b**, $dI/dV(\mathbf{r}, 0.42\text{mV})$ map of the same region as (a), showing the real-space QPI pattern. **c**, $dI/dV(\mathbf{r}, -0.42\text{mV})$ map of the same region as (a), showing the real-space QPI pattern. **d**, FT of $Z(\mathbf{r}, |E|) \equiv \frac{dI/dV(\mathbf{r}, +E)}{dI/dV(\mathbf{r}, -E)}$. **e**, FT of $S(\mathbf{r}, |E|) \equiv L(\mathbf{r}, E) + L(\mathbf{r}, -E)$, showing asymmetric $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ along different directions. **f**, Line profiles extracted from (e) along the dotted lines for the $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions, respectively, revealing different length of the $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$, which indicate the chirality of $q_i^{H_m}$ ($i = 1, 2, 3; m = I, II, III$). The different lengths of $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ are guided by dotted curves.

Recommendation. The manuscript addresses an important and timely problem and presents extensive experimental work. However, the central claim—the identification of a chiral-nematic Fermi liquid as a parent state—relies on subtle symmetry analysis that is not yet sufficiently supported.

I therefore recommend a major revision. The issues outlined above, particularly those concerning data processing, symmetry interpretation, and robustness of the QPI analysis, must be addressed before the conclusions can be considered convincing.

Response: We sincerely thank the Reviewer for the careful evaluation of our manuscript and for recognizing the importance and timeliness of this work. We also appreciate the Reviewer's constructive comments and detailed suggestions regarding the symmetry analysis, data processing procedures, and robustness of the QPI interpretation.

In response, we have carefully revised the manuscript and substantially expanded both the main text and Supplementary Information. In particular, we have clarified the symmetry analysis in both real space and momentum space, added detailed descriptions of the QPI processing and fitting procedures, performed additional analyses using Feenstra-normalized conductance maps, provided quantitative discussions of the signal-to-noise level and Bragg-vector uncertainties, and included new datasets and supplementary figures to further demonstrate the robustness and reproducibility of the observed symmetry-breaking behavior.

We believe these revisions significantly strengthen the manuscript and clarify the evidence supporting the chiral-nematic Fermi liquid interpretation. We are grateful for the Reviewer's comments, which have helped improve both the clarity and the rigor of the presentation.

In summary, we believe we have carefully addressed all the Reviewers' comments and questions by adding new data and discussions, as well as clarifying revisions. Once again, we sincerely thank all Reviewers for their insightful, constructive and critical comments/questions, which have helped us to further strengthen the manuscript, which, we hope, now makes it suitable for publication in *Nature Communications*.

Responses to the reviewers' comments

We are grateful to the Reviewers for their careful reading of our manuscript and for their encouraging assessment of the work. The comments raised during the review process have allowed us to clarify several important aspects of the study. In response to Reviewer #2, we have expanded the discussion of the k_z selection, impurity-related effects, and the difference between the mass enhancement values obtained from QPI and ARPES. In response to Reviewer #3, we have arranged for the data to be made available through an open-access repository.

All points raised by the Reviewers have been carefully considered, and the manuscript has been revised accordingly. We hope that the revised version and the detailed responses below adequately address the remaining concerns.

Summary of major changes to the manuscript:

- We have added discussions to clarify that the use of the $k_z = \pi$ constant-energy contour is an approximation, rather than a quantitative fit to the full experimental Fermi surface.
- We have included T-matrix simulations of impurities with strong scattering potential on sublattices of kagome lattice (new Figs. S18-20) as a new addition to the Supplementary Information (Section H), and we have expanded our discussion to address the potential influence of strong scatters on the experimental results.
- We have included a discussion of the potential origins of the different mass enhancement values obtained in our experiments compared with ARPES results.
- We have revised the data availability statement and will deposit the data from this work in a public repository upon publication.

Below, the comments from the reviewers are included in black *italic* typeface. Our responses are in regular blue typeface. The changes to the text in the revised manuscript are discussed or quoted in red.

Response to the Reviewer #2

I have read the author's reply to my comments and their revised manuscript. The authors have addressed comments 1 and 4 of my initial report. However, I find their responses to points 2 (the choice of K_z), 3 (the role of impurities), or 5 (the mass discrepancies) less persuasive. I will provide some comments below on why I am not persuaded. But I first want to emphasize that these points are not necessarily reasons not to publish the work (which I view as being more experimentally focused) provided the authors provide frank discussions of these points and how they might affect the conclusions.

Response: We sincerely thank the Reviewer for the thoughtful comments on our previous response and revised manuscript. We appreciate the Reviewer's emphasis that these issues do not necessarily preclude publication, provided that the underlying assumptions and limitations are discussed transparently. Following the Reviewer's suggestion, we have expanded the discussion of the issues raised below and clarified their possible implications for the interpretation of our results and conclusions. Importantly, while these considerations highlight the limitations of the present modeling, they may not affect the main experimental observations or the central conclusions of this work.

Comment 1: *Choice of K_z : The authors essentially argue that, experimentally, the system is two-dimensional, and the ARPES data agree with the dispersion at $k_z = \pi$. This is not a justification for taking the $k_z = \pi$ value from the ab initio calculations. This kind of discrepancy occurs frequently in QPI modeling, particularly in correlated materials, where DFT tends to overestimate screening. One approach is to use an empirical fit to ARPES data to model the QPI data. In essence, this is what the authors are doing by cherry-picking the k_z value that best agrees with their data. If they wish to do this rather than model the entire k_z dispersion, then they should state it clearly in the text so readers are alerted to the approximations and assumptions being used. As the paper is written, it implies stronger agreement between DFT and the experiments, when, in fact, they are ad hoc, selecting one k_z value.*

Response 1: We thank the Reviewer for this important comment. We agree that the choice of $k_z = \pi$ should be stated more explicitly and that our comparison should not be interpreted as a quantitative claim of full agreement between the DFT Fermi surface and the experimental QPI data. Rather, the calculated CEC at $k_z = \pi$ is used as an approximate reference to identify the dominant orbital character and the possible scattering channels, and to compare the symmetry properties of the calculated electronic structure with the experimentally observed QPI patterns.

Following the Reviewer's suggestion, we have revised the text to clearly state this approximation and the assumptions involved. We have also softened the related statements throughout the manuscript to avoid implying that the $k_z = \pi$ DFT CEC provides a quantitative fit to the measured QPI dispersion.

“By comparing with the calculated CEC (Fig. 1c) at $k_z = \pi$ near the Fermi level²², we attribute $\mathbf{q}_1$ (Fig. 1g) to intra-pocket scattering within the Sb p_z orbital-derived pocket (blue circular pocket α in Fig. 1c), while $\mathbf{q}_2$ and $\mathbf{q}_3$ (Fig. 1g) originate from inter-pocket scattering between in-plane V d orbital-derived pockets (red triangular pockets δ in Fig. 1c). We emphasize that the use of the $k_z = \pi$ CEC is an approximation adopted to provide an orbital- and symmetry-based reference for the QPI analysis, rather than a quantitative fit to the full experimental Fermi surface. Therefore, our comparison should be understood as a qualitative guide for identifying the relevant scattering channels and their symmetry properties. Note that consistent with previous results, the out-of-plane V d orbital-derived FSs (green lines in Fig. 1c) are invisible (Fig. 1g) in the coherent QPI patterns²².”

“...and replot the two sets of FSs as a function of θ measured from the crystallographic directions (Fig. 2e, left panel). Here again, the selected DFT contours are used only as a qualitative reference to illustrate the symmetry variation. We then conjecture that the correlation effects beyond the DFT theory can be described by a d -wave Pomeranchuk distortion...”

Comment 2: *Impurities:* The author’s response cites early QPI theory, in which the full intensity is approximated by a factorized expression. This expression is a weak-coupling approximation, where the JDOS provides a better approximation to the QPI, but several theoretical works since then have shown that impurity effects can be important, particularly for strong scatterers. I believe the paper would be strengthened considerably by treating a proper T-matrix calculation, even for a point defect on one of the sublattices. I understand that the authors might like to keep the theory simple, but these calculations are not that hard for point-like defects.

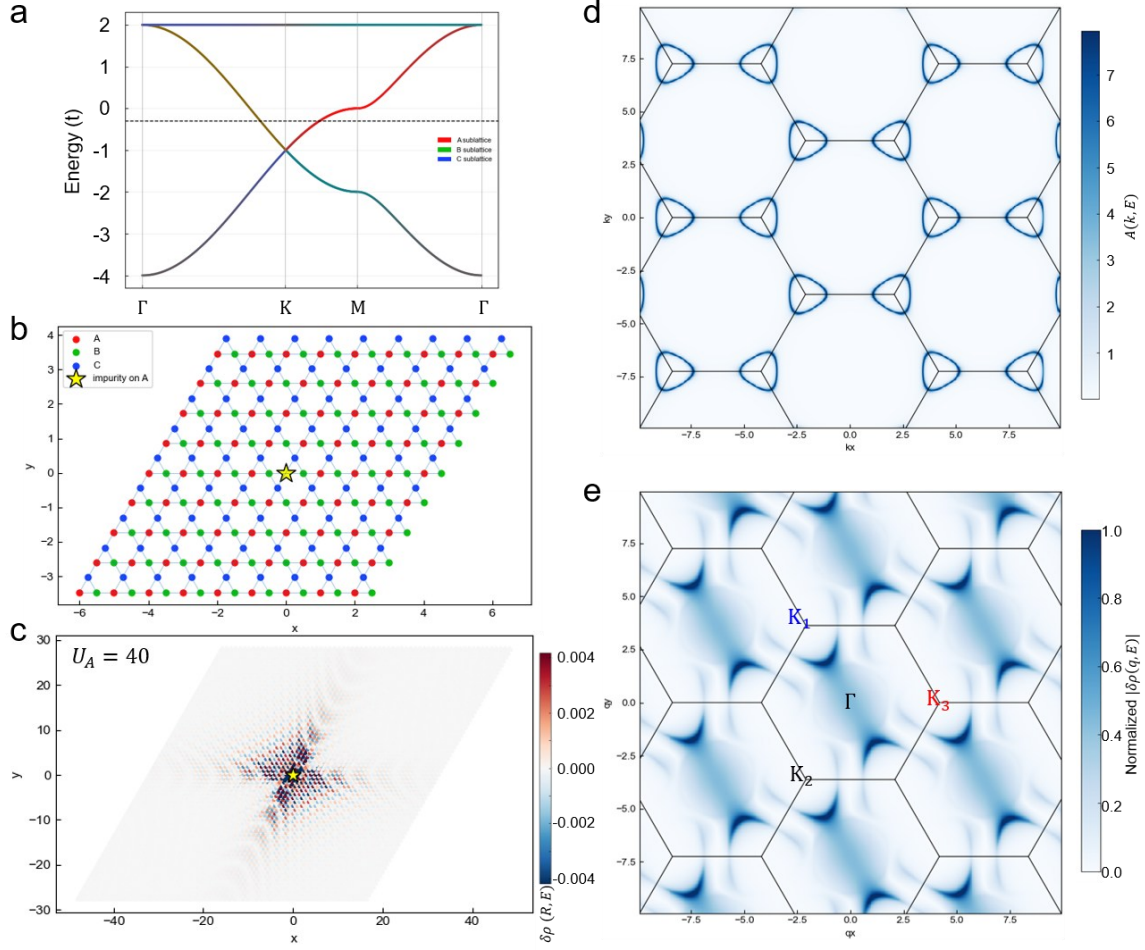
Response 2: We thank the Reviewer for this important suggestion. We agree that the factorized expression used in our previous discussion is closely related to a weak-scattering approximation and does not generally capture the full impurity-strength dependence or the repeated-scattering effects associated with strong impurities. Strong impurity scattering can, in general, modify the QPI intensity and may, in some models, shift the apparent positions of QPI maxima relative to weak-scattering approximations such as the JDOS [Hong, S.-J. et al. *J. Phys. Chem. C* **125**, 7488–7494 (2021)]. We have therefore carried out a non-perturbative T-matrix calculation for strong local defects in a kagome lattice, beginning with the point-defect scenario suggested by the Reviewer.

To perform this controlled test, we construct a minimal single-orbital, three-sublattice kagome tight-binding model (new Fig. S18b). We select the constant-energy contour at $E/t = -0.3$, where the calculated contour consists of rounded triangular pockets that qualitatively resemble the momentum-space geometry relevant to the experimental QPI features (Fig. S18d). The selected energy is used to provide the relevant pocket topology for this illustrative calculation, rather than as a quantitative fit to the experimental band structure. This model is intended as a minimal test of a strong sublattice-selective point defect and is not meant to identify the

microscopic defect species or its precise scattering potential in the experiment.

Without loss of generality, the strong onsite impurity potential is placed at the origin on kagome sublattices in real space and the scattering potential acts in the sublattice-resolved channel according to the sublattice content distribution in momentum space. The impurity is treated using the full T-matrix, which resums repeated scattering from the local defect to all orders. We calculate both the impurity-induced real-space LDOS modulation and the corresponding momentum-space QPI response. A repeated-zone representation is used for the reciprocal-space QPI plots. The calculation details and parameters are provided in Section H of the Supplementary Information. In the following, we consider the QPI patterns obtained from three different impurity-scattering scenarios: (i) a single impurity on sublattice A; (ii) a three-site local impurity cluster with moderate sublattice anisotropy; (iii) the same local cluster with a more strongly anisotropic scattering potential. These calculations show that sufficiently strong and anisotropic local scattering can produce direction-dependent shifts of the apparent QPI maxima. However, these shifts depend sensitively on the local impurity potentials and do not naturally account for the robust symmetry-breaking geometry observed experimentally.

(i) Single point defect on sublattice A. As shown in Fig. S18, a strong point defect on the A sublattice produces anisotropic real-space LDOS oscillations with an approximate twofold character (Fig. S18c), consistent with the local reduction of the kagome-lattice symmetry induced by an A-sublattice impurity (Fig. S18b). In momentum space, the impurity redistributes the QPI spectral weight and reduces the sixfold symmetry of the response into a predominantly twofold pattern (Fig. S18e). However, within the present kagome model and the representative strong-scattering parameters examined here, the resulting QPI response does not reproduce the distorted and tilted triangular q-vector geometry observed experimentally, which reflects the simultaneous breaking of rotational and mirror symmetries.

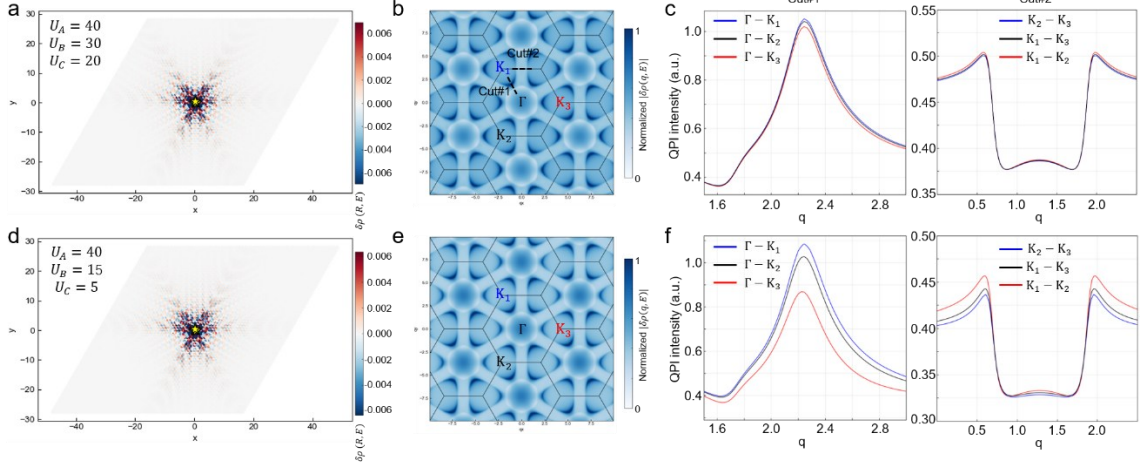


New Fig. S18. T-matrix simulation of a point defect on one sublattice of a kagome lattice. **a**, Band structure of the single-orbital, three-sublattice kagome tight-binding model, with the colors indicating the A-, B-, and C-sublattice weights. **b**, Schematic of the kagome model with a strong onsite point defect placed at the origin on sublattice A. **c**, Impurity-induced real-space LDOS modulation, $\delta\rho(\mathbf{R}, E)$, obtained from the T-matrix calculation. **d**, Constant-energy contour of the clean kagome model at $E/t = -0.3$. **e**, Corresponding momentum-space QPI pattern $|\delta\rho(\mathbf{q}, E)|$. The simulation parameters are $t = 1$, $\eta/t = 0.04$, $E/t = -1.6$, and $U_A/t = 40$.

(ii) Three-site impurity cluster with moderate anisotropy. We consider a three-site impurity configuration with varying onsite potentials to the A, B, and C sublattices within one kagome unit cell. This three-sublattice impurity configuration is introduced to break both rotational and mirror symmetries locally. For $(U_A, U_B, U_C)/t = (40, 30, 20)$, the real-space LDOS oscillations break both symmetries (new Fig. S19a), whereas the corresponding momentum-space QPI pattern primarily exhibits direction-dependent variations in spectral weight (Figs. S19b,c). The line profiles along the three Γ - K_i and K_i - K_j directions show different peak amplitudes, while the peak positions remain nearly unchanged. The distorted and tilted triangular $\mathbf{q}$ -vector geometry observed experimentally is still not reproduced.

(iii) Three-site impurity cluster with strong anisotropy. We further increase the anisotropy

of the local scattering potential to $(U_A, U_B, U_C)/t = (40, 15, 5)$. In this case, the calculated line profiles exhibit not only direction-dependent variations in spectral weight but also apparent shifts of the QPI maxima (Fig. S19f). This result confirms that a sufficiently strong and highly anisotropic impurity potential can, under particular conditions, affect the apparent QPI peak positions, consistent with previous strong-scattering T-matrix studies.



New Fig. S19. T-matrix simulation of a three-sublattice anisotropic impurity configuration on a kagome lattice. **a**, Impurity-induced real-space LDOS modulation, $\delta\rho(\mathbf{R}, E)$, obtained from the T-matrix calculation with parameters $U_A/t = 40$, $U_B/t = 30$, $U_C/t = 20$. **b**, Corresponding momentum-space QPI pattern, $|\delta\rho(\mathbf{q}, E)|$, for the LDOS modulation in **(a)**. **c**, Line profiles (cut#1 and cut#2) extract from **(b)** along the three $\Gamma - K_i$ directions (left) and $K_i - K_j$ directions (right). **d**, Impurity-induced real-space LDOS modulation, $\delta\rho(\mathbf{R}, E)$, obtained from the T-matrix calculation with parameters $U_A/t = 40$, $U_B/t = 15$, $U_C/t = 5$. **e**, Corresponding momentum-space QPI pattern, $|\delta\rho(\mathbf{q}, E)|$, for the LDOS modulation in **(d)**. **f**, Line profiles (cut#1 and cut#2) extract from **(e)** along the three $\Gamma - K_i$ directions (left) and $K_i - K_j$ directions (right).

Our calculations therefore show that strong impurities are, in principle, able to modify the apparent QPI maxima. However, producing pronounced direction-dependent peak shifts within this impurity scenario requires a strongly anisotropic local scattering potential, and the resulting response still does not naturally generate the specific distorted and tilted triangular q-vector geometry observed experimentally. To distinguish the key features in our experimental observations, we further emphasize two points in our observations.

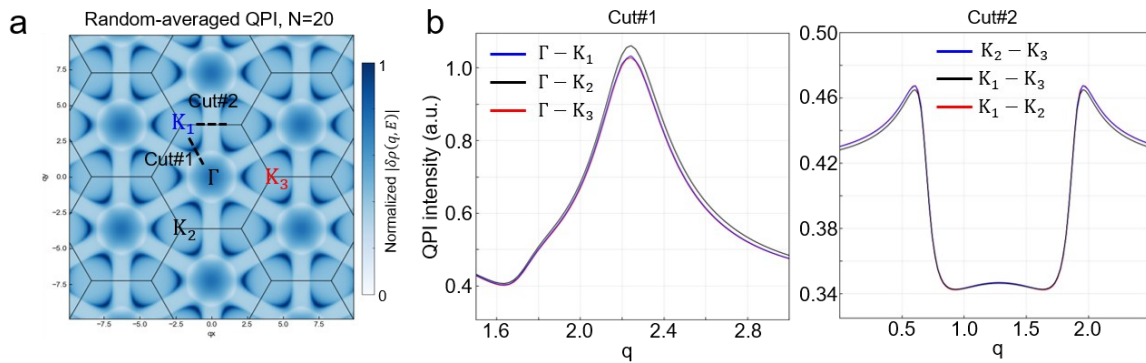
First, the calculated impurity response depends sensitively on the relative sublattice scattering potentials, whereas the experimental q-vector anisotropy is robust. The primary experimental observation is a reproducible anisotropy in both the momentum-space positions (Figs. 2c, d) and dispersions (Figs. 3c, d) of the QPI features. It is observed over large fields of view, across different regions (Fig. S1), different samples (Figs. S3–S7 and S16–S17), and different surface terminations (Fig. S14). An impurity-based explanation would therefore require a population of strongly anisotropic defects that consistently selects the same symmetry-breaking direction

under all these experimental conditions. However, no such dominant defect population with a common orientation or spatial arrangement is evident in the corresponding topographic images or dI/dV maps (Fig. S13).

Second, QPI originates from the phase-coherent interference between incident and impurity-scattered quasiparticle waves. Each individual defect can generate a coherent local QPI response. In a realistic multi-defect environment, however, random defect positions introduce different translational phase factors, while random local symmetry-breaking configurations generate anisotropic responses with different symmetry orientations. These contributions do not naturally add coherently along the same global momentum-space direction and are therefore expected to be reduced by spatial or disorder averaging.

To isolate the effect of random local impurity configurations, we further average the calculated QPI responses over 20 independently generated configurations with random permutations of the sublattice potentials $(U_A, U_B, U_C)/t = (40, 15, 5)$. This calculation represents a configuration average over local sublattice-potential arrangements at a fixed impurity-cluster position. It is not a coherent simulation of many impurities at random real-space positions in the same field of view. As shown in Fig. S20, both the direction-dependent anisotropy and the apparent shifts of the QPI maxima are strongly reduced in the configuration-averaged response.

These results do not exclude local impurity-specific effects, but indicate that randomly configured strong local defects alone may not fully account for the robust global momentum-space symmetry breaking observed experimentally. The calculations are intended as controlled tests of the strong sublattice-impurity scenario raised by the Reviewer, rather than as microscopic models of specific defect species and configurations, which would require additional experimental identification.



New Fig. S20. T-matrix simulation of configuration-averaged QPI magnitude. a, Momentum-space QPI pattern, $|\delta\rho(q, E)|$, averaged over 20 independently generated impurity configurations with randomly permuted sublattice potentials $(U_A, U_B, U_C)/t = (40, 15, 5)$. **b,** Line profiles extract from (a) along the three $\Gamma - K_i$ directions (left) and $K_i - K_j$ directions (right).

The calculation details have been included in Section H of the Supplementary Information. We have also added a discussion of the possible role of strong point impurities and its implications for our conclusions in the revised manuscript.

“...Both the length variations in q_1 along the three different directions (Supplementary Figs. S6e and S7e), as well as the tilt of the q_3 feature (Supplementary Figs. S6d and S7d), can be observed, which are consistent with the behavior in the Ti doped samples. Although strong impurities may modify the QPI response³⁵, our T-matrix calculations show that, within the present kagome model and the representative strong-scattering parameters examined, sublattice-selective and anisotropic point-defect configurations do not naturally reproduce the distorted and tilted triangular q-vector geometry observed experimentally (Figs. S18–S20). Moreover, a defect-based explanation would require a dominant defect population with a common local symmetry or preferred orientation, or a spatially correlated defect configuration that consistently selects the same symmetry-breaking direction across different samples and surface terminations. No such dominant or correlated defect population is evident in the corresponding topographic images or dI/dV maps (Fig. S13). Thus, our experimental observations and simulations suggest that randomly configured strong point defects alone may not fully account for the observed momentum-space symmetry breaking.”

Section H. T-matrix simulation for a sublattice impurity in a kagome tight-binding model

To examine the effect of a strong point-like impurity on the QPI pattern, we performed a T-matrix calculation (Wang, Q.-H. & Lee, D.-H. *Phys. Rev. B* 67, 020511 (2003); Balatsky, A. V., Vekhter, I. & Zhu, J.-X. *Rev. Mod. Phys.* 78, 373-433 (2006); Hong, S.-J. et. al. *J. Phys. Chem. C* **125**, 7488–7494 (2021)) based on a minimal single-orbital kagome tight-binding model. The model contains three sublattices, A , B , and C , in each unit cell.

The nearest-neighbor kagome Hamiltonian in the sublattice basis (A, B, C) is

$$H(k) = \begin{pmatrix} -\mu & H_{AB}(k) & H_{AC}(k) \\ H_{AB}^*(k) & -\mu & H_{BC}(k) \\ H_{AC}^*(k) & H_{BC}^*(k) & -\mu \end{pmatrix},$$

where

$$H_{AB}(k) = -t[1 + \exp(-ik \cdot a_1)],$$

$$H_{AC}(k) = -t[1 + \exp(-ik \cdot a_2)],$$

and

$$H_{BC}(k) = -t[1 + \exp(ik \cdot (a_1 - a_2))].$$

Here, t is the nearest-neighbor hopping, μ is the chemical potential, and a_1 and a_2 are the triangular Bravais lattice vectors. The retarded Green function of the clean system is

$$G_0(k, E) = [(E + i\eta)I - H(k)]^{-1},$$

where η is a small positive broadening. The constant-energy contour is visualized from the spectral function

$$A(\mathbf{k}, E) = -\frac{1}{\pi} \text{ImTr}[W G_0(\mathbf{k}, E)],$$

where

$$W = \begin{pmatrix} w_A & 0 & 0 \\ 0 & w_B & 0 \\ 0 & 0 & w_C \end{pmatrix}$$

is a diagonal matrix describing the relative STM tunneling weights on the three sublattices.

H.1. Single-sublattice impurity

A local impurity on sublattice α is modeled by an onsite potential

$$V = U |\alpha\rangle\langle\alpha|.$$

For example, for an impurity on the A sublattice,

$$V_A = \begin{pmatrix} U_A & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}.$$

The local clean Green function is obtained by averaging over momentum,

$$g_0(E) = \frac{1}{N_{\mathbf{k}}} \sum_{\mathbf{k}} G_0(\mathbf{k}, E).$$

The impurity T matrix is then

$$T(E) = [I - V g_0(E)]^{-1} V.$$

This expression includes repeated scattering from the impurity to all orders,

$$T = V + V g_0 V + V g_0 V g_0 V + \dots,$$

and therefore goes beyond the Born approximation.

The direct T-matrix QPI is calculated from the impurity-induced Green-function correction. We first define

$$\Lambda(\mathbf{q}, E) = \frac{1}{N_{\mathbf{k}}} \sum_{\mathbf{k}} G_0(\mathbf{k}, E) T(E) G_0(\mathbf{k} + \mathbf{q}, E).$$

Since the real-space LDOS modulation is a real quantity, its Fourier component satisfies

$$\delta\rho(-\mathbf{q}, E) = \delta\rho^*(\mathbf{q}, E).$$

Accordingly, the complex Fourier component of the impurity-induced LDOS is evaluated as

$$\delta\rho(\mathbf{q}, E) = -\frac{1}{2\pi i} \text{Tr}\{W[\Lambda(\mathbf{q}, E) - \Lambda^\dagger(-\mathbf{q}, E)]\}.$$

In the figures, we plot the QPI amplitude,

$$|\delta\rho(\mathbf{q}, E)|.$$

For compact notation, this direct QPI response is often written in the equivalent form

$$\delta\rho(\mathbf{q}, E) \sim -\frac{1}{\pi} \text{Im} \sum_{\mathbf{k}} \text{Tr} [W G_0(\mathbf{k}, E) T(E) G_0(\mathbf{k} + \mathbf{q}, E)],$$

with the understanding that the Hermitian Fourier relation between $\mathbf{q}$ and $-\mathbf{q}$ is enforced in the numerical implementation.

The real-space LDOS modulation is calculated from the same T matrix. The real-space Green function is

$$G_0(\mathbf{R}, E) = \frac{1}{N_{\mathbf{k}}} \sum_{\mathbf{k}} \exp(i\mathbf{k} \cdot \mathbf{R}) G_0(\mathbf{k}, E).$$

For a single impurity at $\mathbf{R}_{\text{imp}}$, the impurity-induced Green-function correction is

$$\delta G(\mathbf{R}, \mathbf{R}; E) = G_0(\mathbf{R} - \mathbf{R}_{\text{imp}}, E) T(E) G_0(\mathbf{R}_{\text{imp}} - \mathbf{R}, E),$$

and the LDOS modulation is

$$\delta\rho(\mathbf{R}, E) = -\frac{1}{\pi} \text{Im} \text{Tr} [W \delta G(\mathbf{R}, \mathbf{R}; E)].$$

This procedure is a periodic full-cell T-matrix FFT-QPI calculation. The impurity-induced LDOS is evaluated on an $N_R \times N_R$ real-space supercell using the T matrix, and the full supercell LDOS is then Fourier transformed. The use of a discrete momentum grid imposes periodic boundary conditions,

$$G_0(\mathbf{R} + N_R \mathbf{a}_1, E) = G_0(\mathbf{R}, E), \quad G_0(\mathbf{R} + N_R \mathbf{a}_2, E) = G_0(\mathbf{R}, E).$$

Equivalently, the impurity cluster is periodically repeated only at the supercell scale $N_R \mathbf{a}_1$ and $N_R \mathbf{a}_2$. For the parameters used here, the supercell is much larger than the plotted real-space field of view, so the artificial interaction between periodic images is minimized.

In the reciprocal-space plots, we use a repeated-zone representation of the QPI response. The calculated QPI map is defined on momenta $\mathbf{q}_0$ inside one primitive reciprocal cell. For a displayed momentum $\mathbf{q}$ outside this cell, we write

$$\mathbf{q} = \mathbf{q}_0 + \mathbf{G}, \quad \mathbf{G} = m\mathbf{b}_1 + n\mathbf{b}_2,$$

and plot

$$Q_{\text{plot}}(\mathbf{q}, E) = Q_{\text{cell}}(\mathbf{q}_0, E).$$

Therefore,

$$Q_{\text{plot}}(\mathbf{q} + \mathbf{G}, E) = Q_{\text{plot}}(\mathbf{q}, E).$$

No intra-unit-cell basis phase factor $\exp(-i\mathbf{q} \cdot \boldsymbol{\tau}_a)$ is included in this representation. This convention emphasizes the scattering-vector geometry determined by the kagome constant-energy contour.

H.2. Multi-impurity and multi-sublattice impurity configurations

To test whether a small cluster of nearby strong scatterers can generate apparent symmetry

breaking in the QPI pattern, we also considered impurity configurations involving two or three neighboring sublattice sites within the same kagome unit cell. The impurity cluster is specified by a set of sites $i = 1, \dots, N_{\text{imp}}$, with unit-cell position $\mathbf{R}_i$, sublattice index $\alpha_i \in \{A, B, C\}$, and onsite potential U_i . In the impurity-site basis, the potential matrix is

$$(V_{\text{imp}})_{ij} = U_i \delta_{ij}.$$

For example, the representative three-sublattice configurations are

$$V_{ABC} = \begin{pmatrix} U_A & 0 & 0 \\ 0 & U_B & 0 \\ 0 & 0 & U_C \end{pmatrix}_{(A,B,C)}.$$

When the sites are chosen within the same unit cell, their relative positions are determined by the kagome basis vectors τ_A , τ_B , and τ_C , rather than by an additional Bravais-lattice translation.

The clean Green function projected onto the impurity sites is

$$(g_{\text{imp}})_{ij}(E) = [G_0(\mathbf{R}_i - \mathbf{R}_j, E)]_{\alpha_i \alpha_j}.$$

The corresponding multi-impurity T matrix is

$$T_{\text{imp}}(E) = [I - V_{\text{imp}} g_{\text{imp}}(E)]^{-1} V_{\text{imp}}.$$

The off-diagonal elements of g_{imp} describe propagation between different impurity sites and sublattice channels. Therefore, even if V_{imp} is diagonal in impurity-site space, the full T matrix generally contains off-diagonal elements due to multiple scattering between impurities.

The impurity-induced Green-function correction at observation site $(\mathbf{R}, a)$ is then

$$\delta G_{aa}(\mathbf{R}, \mathbf{R}; E) = \sum_{i,j} G_0(\mathbf{R} - \mathbf{R}_i, E)_{a\alpha_i} (T_{\text{imp}})_{ij}(E) G_0(\mathbf{R}_j - \mathbf{R}, E)_{\alpha_j a}.$$

The sublattice-resolved LDOS modulation is

$$\delta \rho_a(\mathbf{R}, E) = -\frac{1}{\pi} \text{Im} \delta G_{aa}(\mathbf{R}, \mathbf{R}; E),$$

and the STM-weighted LDOS modulation is

$$\delta \rho(\mathbf{R}, E) = \sum_{a=A,B,C} w_a \delta \rho_a(\mathbf{R}, E).$$

For the multi-impurity calculations, we obtain the q-space QPI by Fourier transforming the impurity-induced LDOS calculated on the full periodic real-space cell,

$$\delta \rho_a(\mathbf{q}, E) = \sum_{\mathbf{R}} \exp(-i\mathbf{q} \cdot \mathbf{R}) \delta \rho_a(\mathbf{R}, E),$$

and

$$Q_{\text{cell}}(\mathbf{q}, E) = \left| \sum_{a=A,B,C} w_a \delta \rho_a(\mathbf{q}, E) \right|.$$

H.3. Numerical parameters and interpretation

For the illustrative calculation shown in Fig. S18, we use $t = 1$, $\mu = 0$, and representative strong-scattering potentials in units of t . For a single A-sublattice impurity, $U_A/t = 40$. For multi-sublattice impurity clusters, we use $U_A/t = 40$, $U_B/t = 15$, and $U_C/t = 5$. The quasiparticle broadening is $\eta/t = 0.04$. The momentum grid is $N_k \times N_k = 280 \times 280$. The periodic real-space cell used for the full-cell FFT-QPI has $N_R \times N_R = 280 \times 280$ kagome unit cells. The finite-field-of-view real-space LDOS map uses $R_{\text{max}} = 32$, corresponding to $(2R_{\text{max}} + 1) \times (2R_{\text{max}} + 1) = 65 \times 65$ unit cells. Periodic boundary conditions are used for the Green function. The STM tunneling weights are $w_A = w_B = w_C = 1$.

(i) Single point defect on sublattice A. As shown in Fig. S18, a strong point defect on the A sublattice produces anisotropic real-space LDOS oscillations with an approximate twofold character (Fig. S18c), consistent with the local reduction of the kagome-lattice symmetry induced by an A-sublattice impurity (Fig. S18b). In momentum space, the impurity redistributes the QPI spectral weight and reduces the sixfold symmetry of the response into a predominantly twofold pattern (Fig. S18e). However, within the present kagome model and the representative strong-scattering parameters examined here, the resulting QPI response does not reproduce the distorted and tilted triangular q-vector geometry observed experimentally, which reflects the simultaneous breaking of rotational and mirror symmetries.

(ii) Three-site impurity cluster with moderate anisotropy. We consider a three-site impurity configuration with varying onsite potentials to the A, B, and C sublattices within one kagome unit cell. This three-sublattice impurity configuration is introduced to break both rotational and mirror symmetries locally. For $(U_A, U_B, U_C)/t = (40, 30, 20)$, the real-space LDOS oscillations break both symmetries (new Fig. S19a), whereas the corresponding momentum-space QPI pattern primarily exhibits direction-dependent variations in spectral weight (Figs. S19b,c). The line profiles along the three Γ - K_i and K_i - K_j directions show different peak amplitudes, while the peak positions remain nearly unchanged. The distorted and tilted triangular q-vector geometry observed experimentally is still not reproduced.

(iii) Three-site impurity cluster with strong anisotropy. We further increase the anisotropy of the local scattering potential to $(U_A, U_B, U_C)/t = (40, 15, 5)$. In this case, the calculated line profiles exhibit not only direction-dependent variations in spectral weight but also apparent shifts of the QPI maxima (Fig. S19f). This result confirms that a sufficiently strong and highly anisotropic impurity potential can, under particular conditions, affect the apparent QPI peak positions, consistent with previous strong-scattering T-matrix studies.

Our calculations therefore show that strong impurities are, in principle, able to modify the apparent QPI maxima. However, producing pronounced direction-dependent peak shifts within this impurity scenario requires a strongly anisotropic local scattering potential, and the resulting response still does not naturally generate the specific distorted and tilted triangular q-vector

geometry observed experimentally. To distinguish the key features in our experimental observations, we further emphasize two points in our observations.

First, the calculated impurity response depends sensitively on the relative sublattice scattering potentials, whereas the experimental q-vector anisotropy is robust. The primary experimental observation is a reproducible anisotropy in both the momentum-space positions (Figs. 2c, d) and dispersions (Figs. 3c, d) of the QPI features. It is observed over large fields of view, across different regions (Fig. S1), different samples (Figs. S3–S7 and S16–S17), and different surface terminations (Fig. S14). An impurity-based explanation would therefore require a population of strongly anisotropic defects that consistently selects the same symmetry-breaking direction under all these experimental conditions. However, no such dominant defect population with a common orientation or spatial arrangement is evident in the corresponding topographic images or dI/dV maps (Fig. S13).

Second, QPI originates from the phase-coherent interference between incident and impurity-scattered quasiparticle waves. Each individual defect can generate a coherent local QPI response. In a realistic multi-defect environment, however, random defect positions introduce different translational phase factors, while random local symmetry-breaking configurations generate anisotropic responses with different symmetry orientations. These contributions do not naturally add coherently along the same global momentum-space direction and are therefore expected to be reduced by spatial or disorder averaging.

To isolate the effect of random local impurity configurations, we further average the calculated QPI responses over 20 independently generated configurations with random permutations of the sublattice potentials $(U_A, U_B, U_C)/t = (40, 15, 5)$. This calculation represents a configuration average over local sublattice-potential arrangements at a fixed impurity-cluster position. It is not a coherent simulation of many impurities at random real-space positions in the same field of view. As shown in Fig. S20, both the direction-dependent anisotropy and the apparent shifts of the QPI maxima are strongly reduced in the configuration-averaged response.

Comment 3: *The discrepancies in the mass: In their reply, the authors emphasize that they are focused on the low-energy dispersion, while the kink analysis of the ARPES bands is more focused on renormalizations at higher energy scales. I disagree with this assertion. In an analysis of kink structures, as in Ref. 32, one extracts the value of λ from the data. The mass enhancement at the Fermi level is related to λ as $m^*/m = (1 + \lambda)$ and should be directly related to the enhancement discussed by the authors. For this reason, I don't believe this discrepancy is due to different energy ranges examined by the two experiments, and their explanation in the revised paper is incorrect. While I agree with the authors that this is not the main point of the paper, it is more than fair to ask them to explain why they think the results don't agree if they are going to compare the mass enhancements obtained in the two experiments.*

Response 3: We thank the Reviewer for this important comment. We agree that, in principle, the mass enhancement at the Fermi level should be directly related to the electron-boson coupling constant through $m^*/m = 1 + \lambda$, and therefore the discrepancy between the STM-

QPI and ARPES estimates deserves a careful discussion. Following the Reviewer's comment, we have removed our previous explanation based on the different energy windows probed by the two techniques and now discuss several alternative possibilities.

First, the ARPES measurements in Ref. 32 were primarily performed on pristine CsV_3Sb_5 and Nb-doped samples, whereas our STM-QPI measurements focus on Ti-doped CsV_3Sb_5 compositions. Since chemical substitution can modify the CDW order, orbital character, and low-energy electronic structure, the effective coupling strength and corresponding mass renormalization may exhibit substantial sample and orbital dependence. In addition, Ti dopants may introduce a hole-doping effect [Yang, H. *et al. Science Bulletin* **67**, 2176–2185 (2022)], which could also contribute to differences in the extracted mass enhancement.

Second, the extraction procedures are intrinsically different in the two experiments. In Ref. 32, the real part of the self-energy was obtained relative to an empirical “bare” band constructed by linearly connecting the measured dispersion near the Fermi level to the dispersion at higher binding energies (100 meV) assuming that this represents the unrenormalized band. In contrast, our analysis uses the DFT-derived band dispersion as the reference for estimating the Fermi-velocity renormalization. Different choices of the underlying bare band can naturally lead to quantitative differences in the extracted mass enhancement. Moreover, our QPI measurements can access both occupied and unoccupied states, whereas conventional ARPES mainly probes occupied states, which may also contribute to the difference.

Finally, ARPES and STM probe different combinations of surface and near-surface electronic states and involve different spatial averaging scales. Although both techniques are highly surface sensitive, subtle differences in surface sensitivity or termination averaging, such as possible contributions from Cs and Sb terminations in ARPES versus the Sb-terminated surface measured in our STM experiments, may also contribute to quantitative differences in the extracted renormalization. In addition, ARPES can have finite sensitivity to electronic states beyond the topmost surface layer, whereas STM is predominantly sensitive to the surface local density of states. Therefore, surface-potential effects may also contribute to the observed difference.

We have revised the manuscript accordingly to present these considerations explicitly and to avoid overinterpreting the quantitative comparison between the two techniques.

“...Furthermore, the reported ARPES data³² show a similarly enhanced renormalization for the δ band compared to the theoretical prediction, in agreement with our QPI results. The mass enhancement extracted from our QPI analysis is lower than that reported by ARPES electron-phonon measurements³². This quantitative difference may arise from several factors. First, the measurements were performed on different compositions: pristine/Nb-doped samples in ARPES and Ti-doped samples in our QPI experiments. Second, the extracted renormalization depends sensitively on the choice of reference bare band; ARPES uses an empirical bare-band construction, whereas our QPI analysis uses DFT-derived dispersions as the reference. Third, QPI can access both occupied and unoccupied states and is predominantly sensitive to the local surface density of states, whereas ARPES mainly probes occupied states with different surface/near-surface averaging. These factors may contribute to the quantitative difference between the two estimates.”

Response to the Reviewer #3

In my previous review, I recommended major revision because the central claim, the identification of a chiral-nematic Fermi liquid as a parent state, relied on subtle symmetry analysis that I felt was not yet sufficiently supported.

The authors have now addressed my concerns in a thorough and constructive manner, in particular through new control measurements, Feenstra-normalized reanalysis, checks on lattice/Bragg-vector effects, and expanded analysis across samples and dopings. Together, these additions make a convincing case that the reported rotational and mirror-symmetry breaking is a genuine observation, rather than an artefact of the intricate experimental and data-processing details involved in QPI analysis.

Response: We sincerely thank the Reviewer for the careful re-evaluation of our revised manuscript and for recognizing that the additional analyses and measurements have addressed the previous concerns. We are pleased that the Reviewer finds the new control measurements, Feenstra-normalized analysis, Bragg-vector checks, and expanded sample and doping studies to provide convincing evidence that the observed rotational and mirror symmetry breaking is intrinsic rather than an artefact of the QPI analysis procedure.

The broader interpretation as a chiral-nematic Fermi-liquid parent state remains, in my view, plausible and well motivated rather than uniquely proven. Further work may clarify its microscopic origin and relation to competing ordered phases, which only adds to the significance of the present results. I am therefore happy to recommend publication.

Response: We sincerely thank the Reviewer for this thoughtful perspective on the broader implications of our work. We agree that the interpretation of the chiral-nematic Fermi liquid as the parent state is currently a well-motivated and experimentally supported scenario. We also share the Reviewer's view that future studies aimed at clarifying its microscopic origin and its relationship to competing ordered phases will further enhance the significance and impact of the present findings.

This does not affect my recommendation, but I would encourage the authors to strengthen the Data Availability statement. Given the nuanced nature of QPI analysis, access to both raw and processed data would substantially improve reproducibility and independent verification of the central claims. Where feasible, these data should be deposited in an appropriate public repository.

Response: We thank the Reviewer for this valuable suggestion regarding reproducibility and data transparency. We fully agree that access to both raw and processed data is particularly important for independent verification of QPI analyses. We will therefore deposit the relevant raw and processed datasets in an appropriate public repository prior to publication and update

the Data Availability statement accordingly.

In summary, we believe we have carefully addressed all the Reviewers' comments and questions by adding new data and discussions, as well as clarifying revisions. Once again, we sincerely thank all Reviewers for their insightful, constructive and critical comments/questions, which have helped us to further strengthen the manuscript, which, we hope, now makes it suitable for publication in *Nature Communications*.

Responses to the reviewers' comments

We are grateful to the Reviewer for recommending publication of our manuscript. We sincerely appreciate the Reviewer's careful evaluation and constructive comments throughout the review process, which have helped us improve the clarity and robustness of the manuscript.

Response to the Reviewer #2

Reviewer #2 (Remarks to the Author):

I am satisfied with the author's reply to my second report and with their revisions. I believe these changes have strengthened both the presentation and robustness of the results and I am happy to recommend publication at this time.

Response: We sincerely thank the Reviewer for recommending publication of our work. We greatly appreciate the Reviewer's thoughtful comments and constructive feedback throughout the review process, which have helped us improve the presentation and strengthen the manuscript.