

Supplementary Information

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

Zihao Huang^{1,2,3}, Zhan Wang¹, Hengxin Tan⁴, Zhen Zhao^{1,2}, Chengmin Shen^{1,2}, Haitao Yang^{1,2}, Bent Weber³, Binghai Yan⁴, Hui Chen^{1,2*}, Ziqiang Wang^{5*}, Hong-Jun Gao^{1,2*}

¹ *Beijing National Center for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, PR China*

² *School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100190, PR China*

³ *School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371, Singapore*

⁴ *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel*

⁵ *Department of Physics, Boston College, Chestnut Hill, MA, USA*

*Correspondence authors, Email address: hjgao@iphy.ac.cn, wangzi@bc.edu, hchenn04@iphy.ac.cn

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Section A. The evolution of the superconductivity

In our previous work¹, we systematically investigated the superconductivity evolution and its dependence on Ti doping, and we briefly summarize the key results here (Supplementary Figure 11). In pristine CsV_3Sb_5 ($x = 0$), the superconducting gap exhibits a V-shaped spectrum 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: 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 (Supplementary Figure 11) emerge from 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 (Supplementary Figure 11) develops directly from the “parent” chiral-nematic state without accompanying long-range CDW order.

Section B. Affine transition and lattice structure symmetry analysis

The affine transformation procedure was applied only to Figs. 2b and 4d for the main text. Such procedures are commonly used in STM studies to remove instrumental drift and scanning nonlinearity². 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.

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.

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.

We further analyze the lattice symmetry directly from the raw (uncorrected) data, as shown in a Supplementary Figure 12. We compare the three Bragg vectors $\mathbf{Q}_A$, $\mathbf{Q}_B$, and $\mathbf{Q}_C$ from the Fourier-transformed topography (Supplementary Figure 12a), and show their line profiles (Supplementary Figure 12b). Gaussian fitting of the peak positions (Supplementary Figure 12c) 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 $\mathbf{q}_2$ 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.

Section C. The role of the impurities

From a theoretical perspective, the QPI signal, $P(q, E) \propto g(q, E)$, can be expressed as^{3,4}:

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

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. Within this framework, the scattering potential of impurities primarily affects the *intensity* of QPI features, while the *positions* of the scattering wave vectors are determined by the underlying electronic structure. 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 Supplementary Figure 13. Experimentally, we identify two dominant types of impurities on the Sb-terminated surface: (i) Sb vacancies (black arrows in Supplementary Figure 13a), and (ii) Ti dopants located beneath the Sb layer (yellow arrows in Supplementary Figure 13a). 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 (Supplementary Figure 13b). The Ti dopants, as established in our previous work¹, 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.

Section D. Lorentzian fitting of the q-dispersions

We analyze the data using Feenstra-normalized⁵⁻⁷ conductance maps

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

The extracted QPI peak positions are obtained from Lorentzian fits with linear background to the momentum-space line profiles:

$$f(x) = A \frac{\gamma^2}{(x - x_0)^2 + \gamma^2} + kx + b$$

When two peaks are close together in the line profiles, a fit using two Lorentzian functions is employed. The fitting curves are shown in Supplementary Figure 2. The error bars were calculated by combining the fitting standard errors and the pixel resolution⁸: $\epsilon_t = \sqrt{\epsilon_s^2 + \epsilon_{pix}^2}$.

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 in order to improve the signal-to-noise ratio.

Section E. Rotational- and mirror-symmetry-breaking QPI on Cs-terminated surface

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 Supplementary Figure 14.

Supplementary Figure 14a shows the pristine Cs-terminated surface immediately after cleaving. The corresponding dI/dV map (Supplementary Figure 14b) exhibits real-space QPI modulations. Fourier transformation of the data reveals the dominant $\mathbf{q}_1$ scattering feature (Supplementary Figure 14c), 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 (Supplementary Figure 14d), where the $\mathbf{q}_1$ 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.

Section F. Estimate of the signal-to-noise ratio and low-frequency signals

To estimate the signal-to-noise ratio of the QPI features, we compare the average peak intensity of the $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ 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.

Regarding the additional ring-like feature appearing slightly inside the $\mathbf{q}_1$ 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.

Interestingly, our QPI simulations in Fig. 2f suggest that an additional inner scattering feature may in principle exist inside the $\mathbf{q}_1$ 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.

Section G. Bogoliubov QPI analysis

We have 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 results are presented in Supplementary Figure 17.

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 effects⁹. However, in the present case the tunneling spectra exhibit an approximately particle–hole symmetric superconducting gap structure (inset of Supplementary Figure 17a). Correspondingly, the dI/dV maps measured at positive and negative biases display very similar spatial patterns (Supplementary Figures 17b–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 (Supplementary Figure S17d).

Instead, motivated by previous Bogoliubov QPI studies¹⁰, 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 (Supplementary Figure 17e) 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 (Supplementary Figure 17f). 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.

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 calculation¹¹⁻¹³ 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

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

where

$$\begin{aligned} H_{AB}(\mathbf{k}) &= -t[1 + \exp(-i\mathbf{k} \cdot \mathbf{a}_1)], \\ H_{AC}(\mathbf{k}) &= -t[1 + \exp(-i\mathbf{k} \cdot \mathbf{a}_2)], \end{aligned}$$

and

$$H_{BC}(\mathbf{k}) = -t[1 + \exp(i\mathbf{k} \cdot (\mathbf{a}_1 - \mathbf{a}_2))].$$

Here, t is the nearest-neighbor hopping, μ is the chemical potential, and $\mathbf{a}_1$ and $\mathbf{a}_2$ are the triangular Bravais lattice vectors. The retarded Green function of the clean system is

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

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,

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

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,

$$T = V + Vg_0V + Vg_0Vg_0V + \dots,$$

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 $\boldsymbol{\tau}_A$, $\boldsymbol{\tau}_B$, and $\boldsymbol{\tau}_C$, 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 Supplementary Figure 18, 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 Supplementary Figure 18, a strong point defect on the A sublattice produces anisotropic real-space LDOS oscillations with an approximate twofold character (Supplementary Figure 18c), consistent with the local reduction of the kagome-lattice symmetry induced by an A-sublattice impurity (Supplementary Figure 18b). In momentum space, the impurity redistributes the QPI spectral weight and reduces the sixfold symmetry of the response into a predominantly twofold pattern (Supplementary Figure 18e). 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 (Supplementary Figure 19a), whereas the corresponding momentum-space QPI pattern primarily exhibits direction-dependent variations in spectral weight (Supplementary Figures 19b,c). The line profiles along the three $\Gamma\text{--}K_i$ and $K_i\text{--}K_j$ 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.

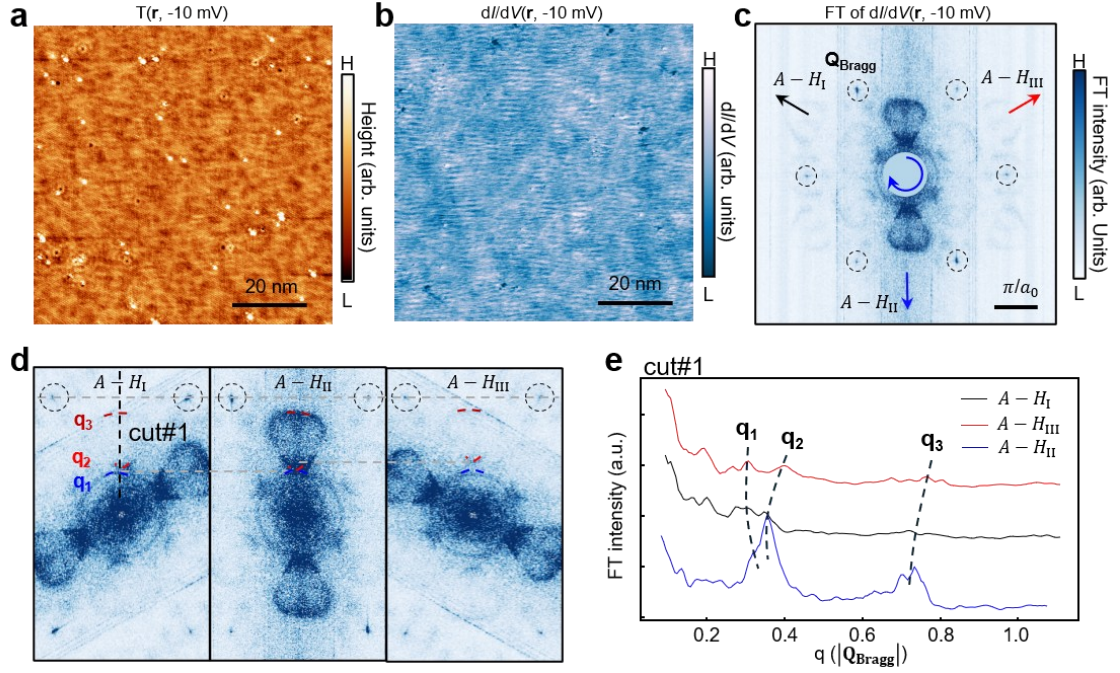
(iii) Three-site impurity cluster with strong anisotropy. We further increase the anisotropy of the local scattering potential to $(U_A, U_B, U_C)/t = (40, 15, 5)$. In this case, the calculated line profiles exhibit not only direction-dependent variations in spectral weight but also apparent shifts of the QPI maxima (Supplementary Figure 19f). 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.

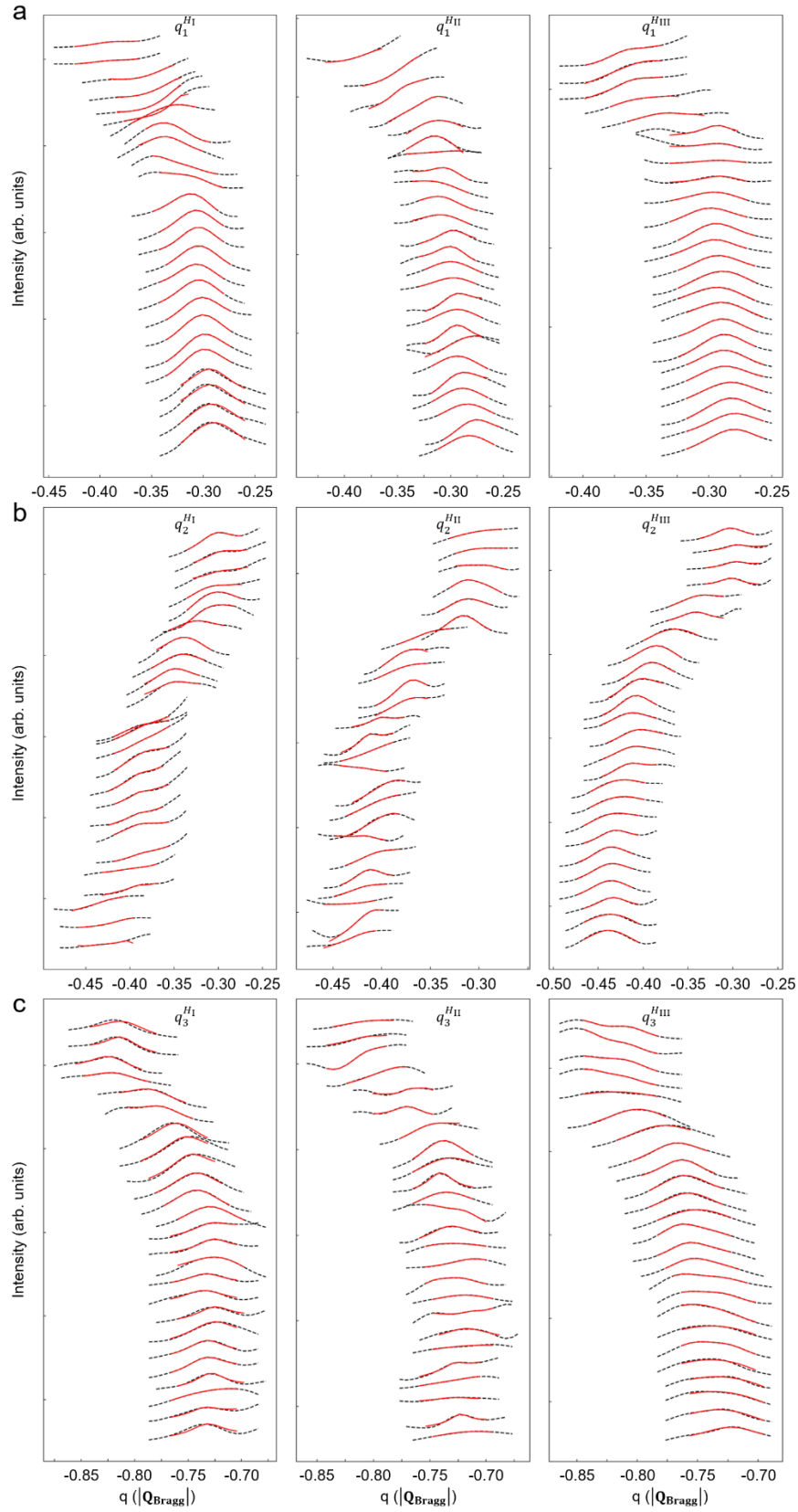
First, the calculated impurity response depends sensitively on the relative sublattice scattering potentials, whereas the experimental q-vector anisotropy is robust. The primary experimental observation is a reproducible anisotropy in both the momentum-space positions (Figs. 2c, d) and dispersions (Figs. 3c, d) of the QPI features. It is observed over large fields of view, across different regions (Supplementary Figure 1), different samples (Supplementary Figures 3–7 and 16–17), and different surface terminations (Supplementary Figure 14). 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 (Supplementary Figure 13).

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.

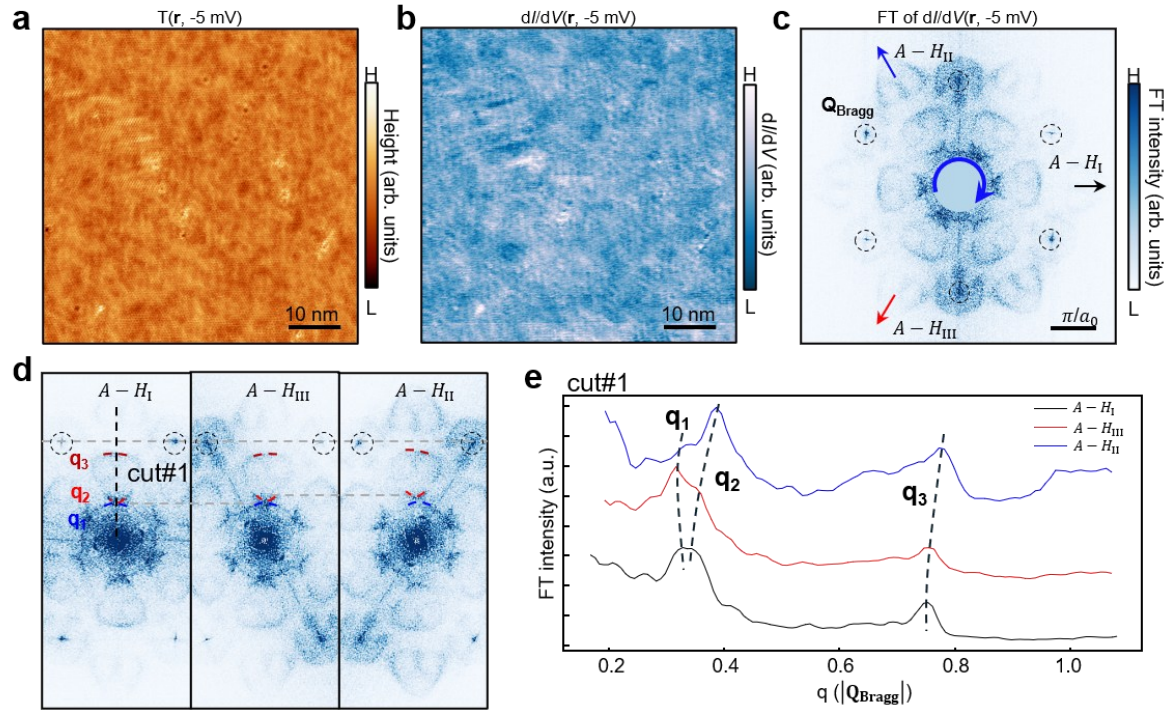
To isolate the effect of random local impurity configurations, we further average the calculated QPI responses over 20 independently generated configurations with random permutations of the sublattice potentials $(U_A, U_B, U_C)/t = (40, 15, 5)$. This calculation represents a configuration average over 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 Supplementary Figure 20, both the direction-dependent anisotropy and the apparent shifts of the QPI maxima are strongly reduced in the configuration-averaged response.



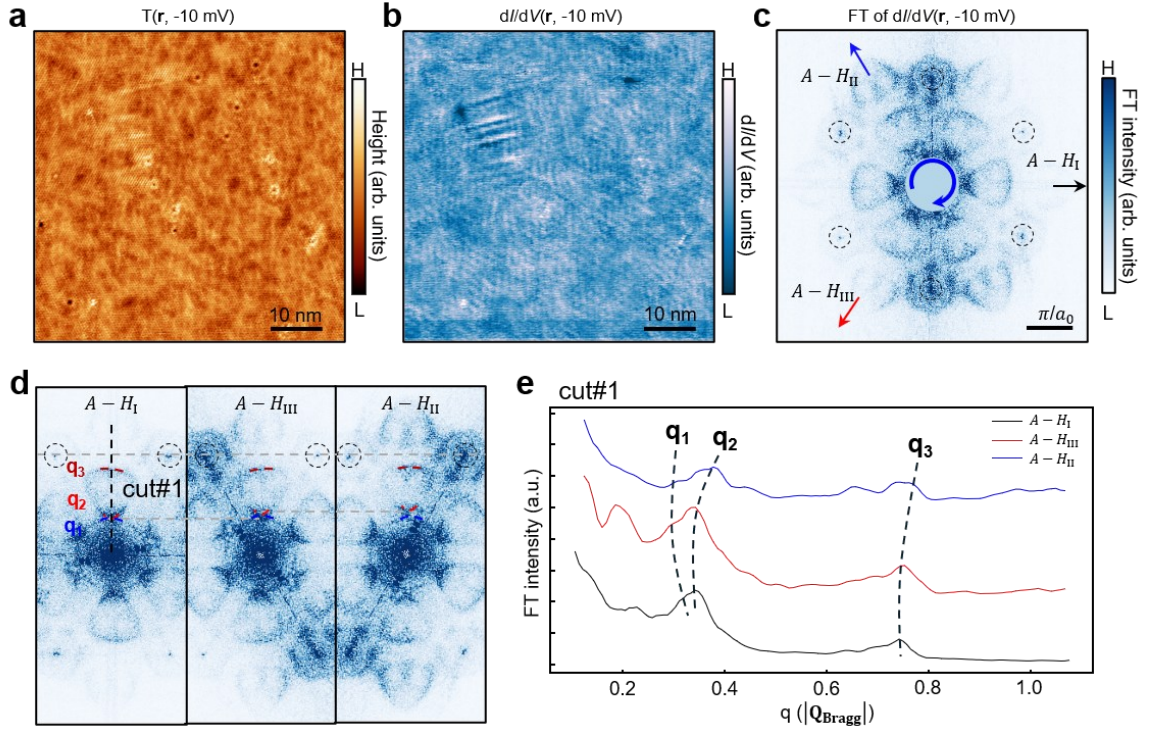
Supplementary Figure 1. Opposite chiral QPI observed in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) at a region near the area shown in Fig. 2. **a**, STM topographic image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$). $V_{\text{bias}} = -10$ mV, $I = 1000$ pA. **b**, dI/dV map of (**a**). $V_{\text{bias}} = -10$ mV, $I = 1000$ pA, $V_{\text{lock-in}} = 0.3$ mV. **c**, FT of (**b**). Black dotted circles mark the scattering vectors of Bragg points. $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions are indicated by black, blue, and red arrows, respectively. The curved arrow denotes the opposite chirality compared to the region of Fig. 2. **d**, The QPI patterns along $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) extracted along $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions in (**c**), showing the different lengths of scattering vectors $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$, respectively, as indicated by dotted curves.



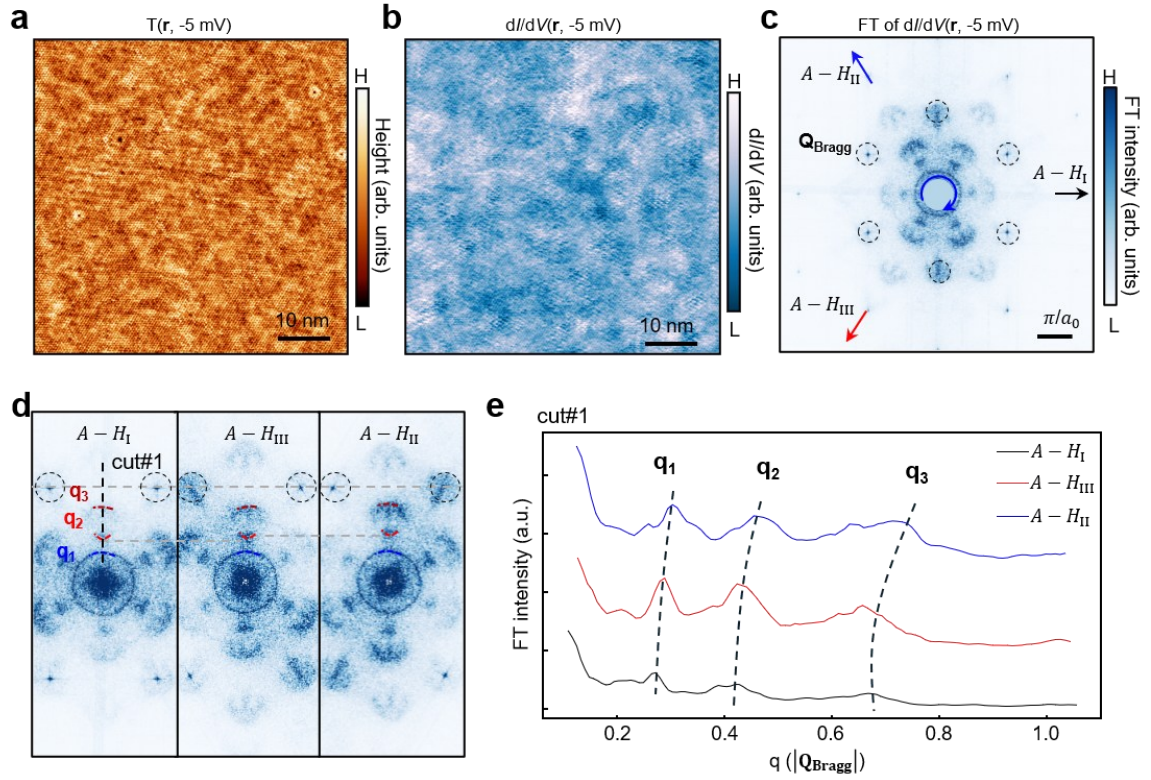
Supplementary Figure 2. Lorentzian fitting of the $\mathbf{q}$ -dispersions. **a-c**, Lorentz fitting (red curves) for $\mathbf{q}_1$ (**a**), $\mathbf{q}_2$ (**b**), and $\mathbf{q}_3$ (**c**) along $A - H_I$ (left), $A - H_{II}$ (middle), and $A - H_{III}$ (right) directions. Black dotted curves are raw data.



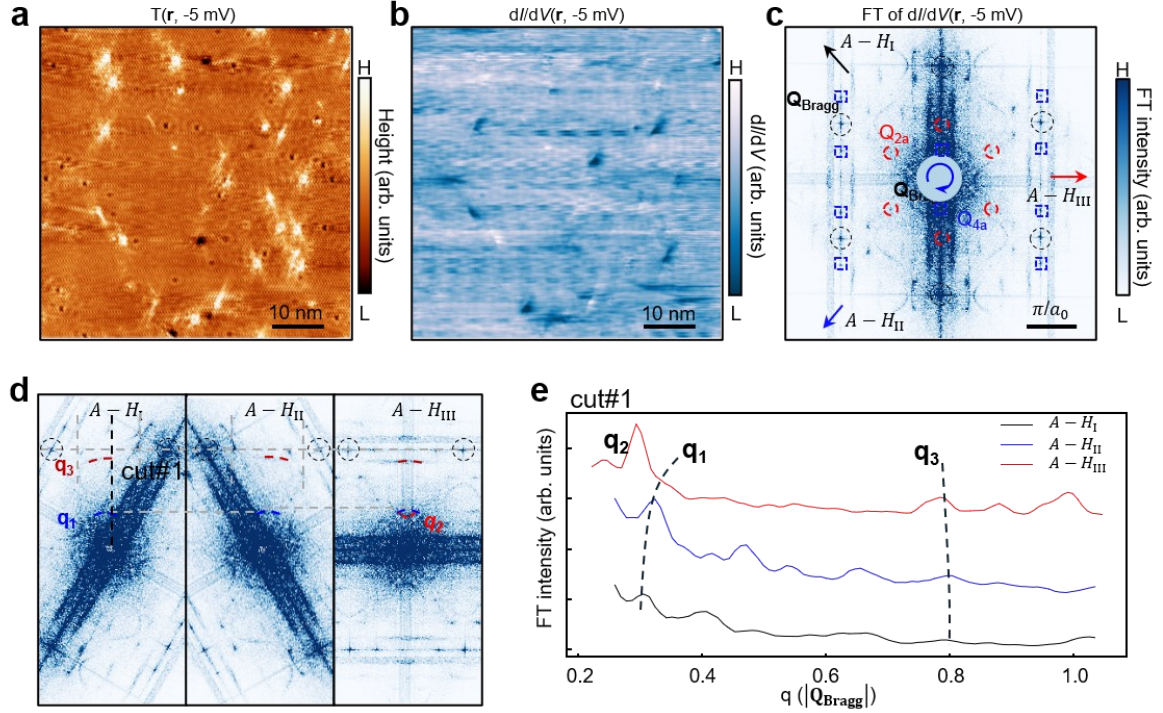
Supplementary Figure 3. Reproducibility of chiral QPI in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) sample #2 at 0.4K. **a**, STM topographic image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) sample #2. $V_{\text{bias}} = -5$ mV, $I = 500$ pA. **b**, dI/dV map of **(a)**. $V_{\text{bias}} = -5$ mV, $I = 500$ pA, $V_{\text{lock-in}} = 0.2$ mV. **c**, FT of **(b)**. Black dotted circles mark the scattering vectors of Bragg points. $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions are indicated by black, blue, and red arrows, respectively. The curved arrow denotes chirality opposite to that in Fig. 2. **d**, The QPI patterns along the $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) extracted along $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions from **(c)**, showing the different lengths of scattering vectors as indicated by dotted curves.



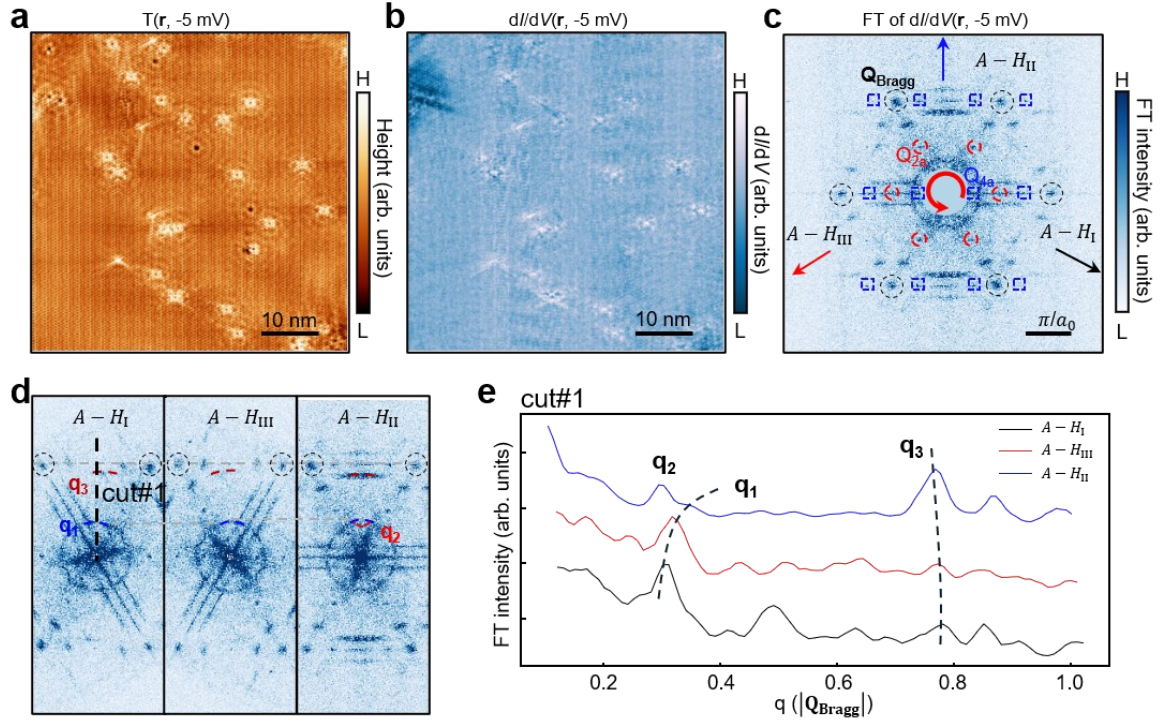
Supplementary Figure 4. Reproducibility chiral QPI in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) sample #2 at 4K. **a**, STM topographic image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) sample #2. $V_{\text{bias}} = -10$ mV, $I = 500$ pA. **b**, dI/dV map of (**a**). $V_{\text{bias}} = -10$ mV, $I = 500$ pA, $V_{\text{lock-in}} = 0.3$ mV. **c**, FT of (**b**). Black dotted circles mark the scattering vectors of Bragg points. $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions are indicated by arrows. The curved arrow denotes chirality opposite to that in Fig. 2. **d**, The QPI patterns along the $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) extracted along $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions from (**c**), showing the different lengths of scattering vectors as indicated by dotted curves.



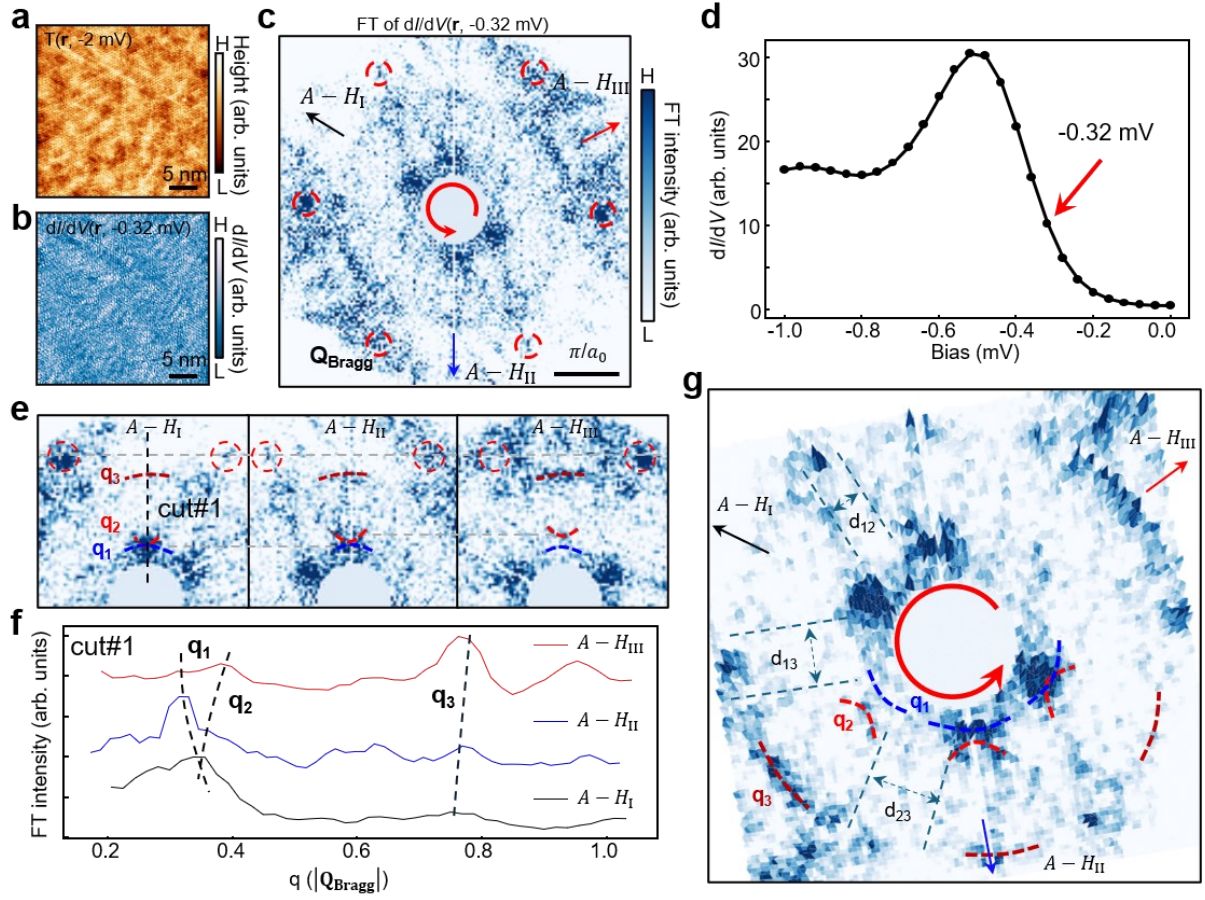
Supplementary Figure 5. Chiral QPI in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.27$) at 0.4K. **a**, STM topographic image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.27$). $V_{\text{bias}} = -5$ mV, $I = 500$ pA. **b**, dI/dV map of (a). $V_{\text{bias}} = -5$ mV, $I = 500$ pA, $V_{\text{lock-in}} = 1$ mV. **c**, FT of (b). Black dotted circles mark the scattering vectors of Bragg points. $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions are indicated by black, blue, and red arrows, respectively. The curved arrow denotes the chirality. **d**, The QPI patterns along the $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) extracted along $A - H_{\text{I}}$, $A - H_{\text{II}}$, and $A - H_{\text{III}}$ directions from (c), showing the different lengths of scattering vectors $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$, respectively, as indicated by dotted curves.



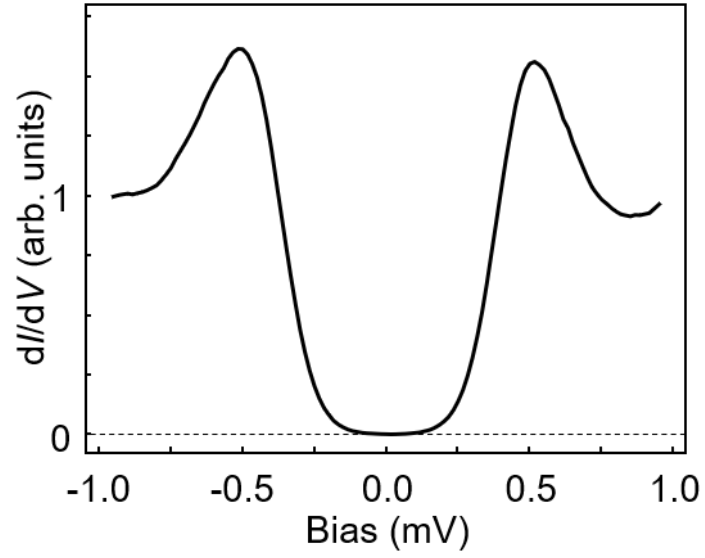
Supplementary Figure 6. Signature of chiral QPI in pristine CsV_3Sb_5 sample #1. **a**, STM topographic image of pristine CsV_3Sb_5 . $V_{\text{bias}} = -5 \text{ mV}$, $I = 500 \text{ pA}$. **b**, dI/dV map of (a). $V_{\text{bias}} = -5 \text{ mV}$, $I = 500 \text{ pA}$, $V_{\text{lock-in}} = 0.25 \text{ mV}$. **c**, FT of (b). Black dotted circles, red dotted circles, and blue dotted rectangles mark the scattering vectors of Bragg points, $2a_0 \times 2a_0$ CDW points, and $1a_0 \times 4a_0$ stripes points, respectively. $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions are indicated by black, blue, and red arrows, respectively. The curved arrow denotes the chirality of QPI patterns. **d**, The QPI patterns along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions in (d), showing the different lengths of $\mathbf{q}_1$ and $\mathbf{q}_3$. The chirality of $\mathbf{q}_1$ and $\mathbf{q}_3$ are indicated by dotted curves.



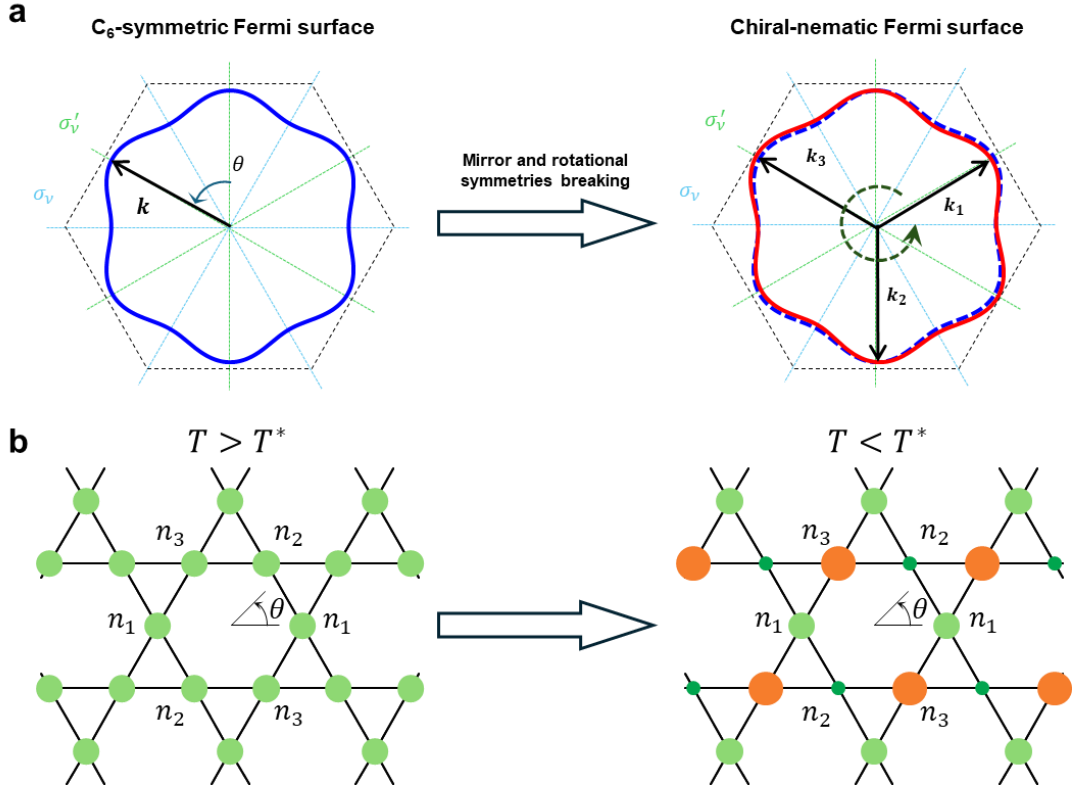
Supplementary Figure 7. Signature of chiral QPI in pristine CsV₃Sb₅ sample #2. **a**, STM topographic image of pristine CsV₃Sb₅. $V_{bias} = -5$ mV, $I = 500$ pA. **b**, dI/dV map of **(a)**. $V_{bias} = -5$ mV, $I = 500$ pA, $V_{lock-in} = 0.25$ mV. **c**, FT of **(b)**. Black dotted circles, red dotted circles, and blue dotted rectangles mark the scattering vectors of Bragg points, $2a_0 \times 2a_0$ CDW points, and $1a_0 \times 4a_0$ stripes points, respectively. $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions are indicated by arrows. The curved arrow denotes the chirality of QPI patterns. **d**, The QPI along $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **e**, Line profiles (cut#1) along $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions in **(d)**, showing the different lengths of q_1 and q_3 . The chirality of q_1 and q_3 are indicated by dotted curves.



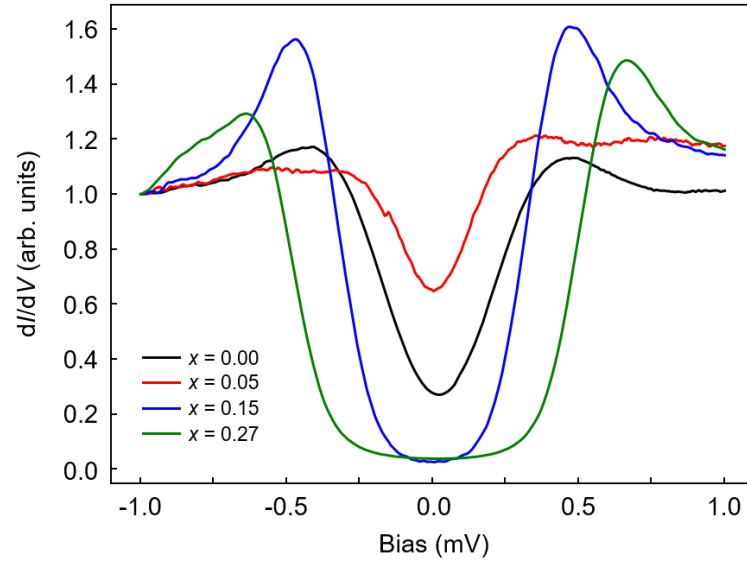
Supplementary Figure 8. Bogoliubov chiral QPI in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$). **a**, STM topographic image of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$). $V_{\text{bias}} = -2$ mV, $I = 500$ pA. **b**, dI/dV map at in-gap bias of -0.32 mV (indicated by arrow in **d**) of **a**. $V_{\text{bias}} = -2$ mV, $I = 500$ pA, $V_{\text{lock-in}} = 0.1$ mV. **c**, FT of **b**. Red dotted circles mark the Bragg scattering vectors. $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions are indicated by the arrows. The curved arrow denotes the observed chirality. **d**, Spatially averaged dI/dV spectrum on **a**. $V_{\text{bias}} = -2$ mV, $I = 500$ pA, $V_{\text{lock-in}} = 0.1$ mV. **e**, The QPI patterns along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions, highlighting the difference in three directions and showing the mirror symmetry breaking of the QPI patterns. **f**, Line profiles (cut#1) along $A-H_I$, $A-H_{II}$, and $A-H_{III}$ directions extracted from **c**, showing the different lengths of scattering vectors $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$, respectively, as indicated by dotted curves. **g**, 3D plot of the zoom-in FT in **c**, highlighting the QPI patterns. The curved arrow indicates the chirality of QPI patterns. The central region is masked for clarity.



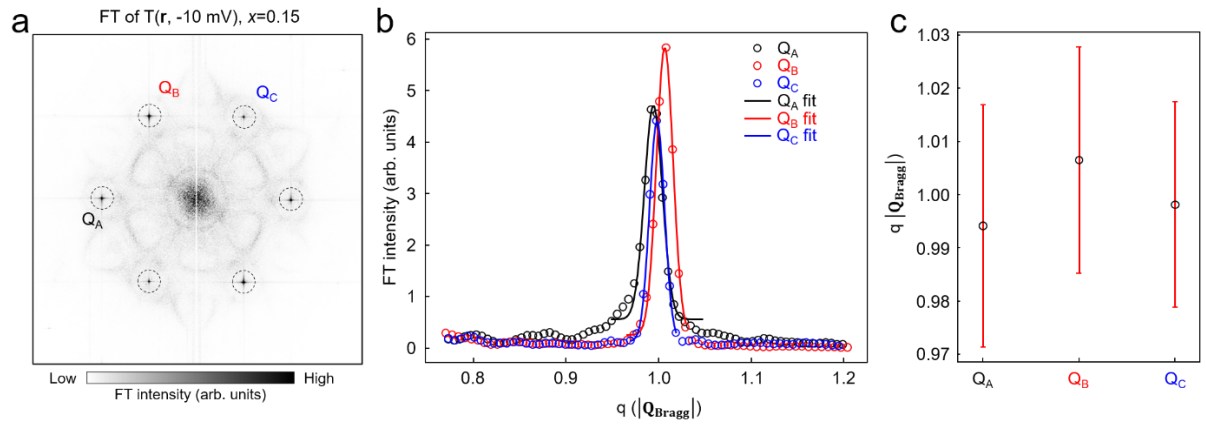
Supplementary Figure 9. U-shaped superconducting gap in $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$). Spatially averaged dI/dV spectrum measured on the Sb surface of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.15$) at 0.4 K and 0 T, showing a U-shaped superconducting gap. $V_{\text{bias}} = -5$ mV, $I = 1000$ pA, $V_{\text{lock-in}} = 0.1$ mV.



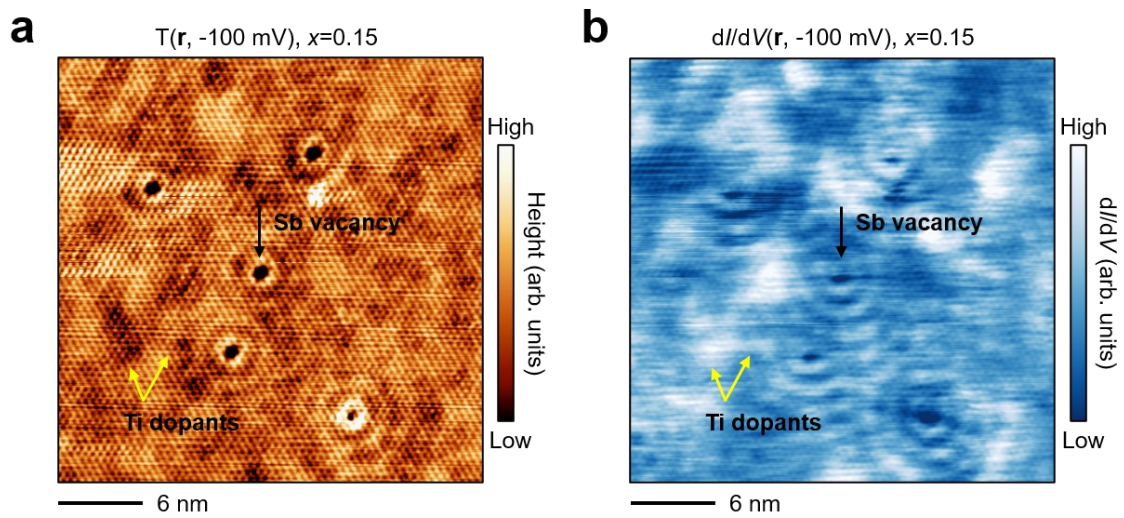
Supplementary Figure 10. Possible origin of the chiral-nematic Fermi liquid state. **a**, Schematic of a chiral FS breaking all mirror symmetries. A general FS with C_6 rotational symmetry is plotted as (left panel) $k_F^0(\theta) = a \cdot \cos(6\theta) + b$ inside a hexagonal Brillouin zone. Two sets of mirror plane perpendicular to the kagome plane are indicated by σ_v and σ'_v . A d -wave Pomeranchuk distortion of the symmetric FS according to $k_F(\theta) = k_F^0(\theta) + \eta \cdot \cos(2\theta - \pi/2)$ produces the chiral FS that breaks all mirror reflections σ_v and σ'_v (right panel). The chirality or handedness can be defined by the progressively decreasing amplitudes of the Fermi wave vectors $k_{3,2,1}$ along the crystal directions in the right panel. **b**, Schematic of a kagome lattice exhibiting chiral-nematic charge order. Within each unit cell, the onsite charge density varies among the three inequivalent sites, illustrated by the atom sizes. The charge density distribution is symmetric with $n_1 = n_2 = n_3$ for $T > T^*$. Below T^* , for generic $\varphi \neq 0, \pm\pi$, all mirror symmetries are broken and the pattern becomes chiral-nematic with $n_1 \neq n_2 \neq n_3$.



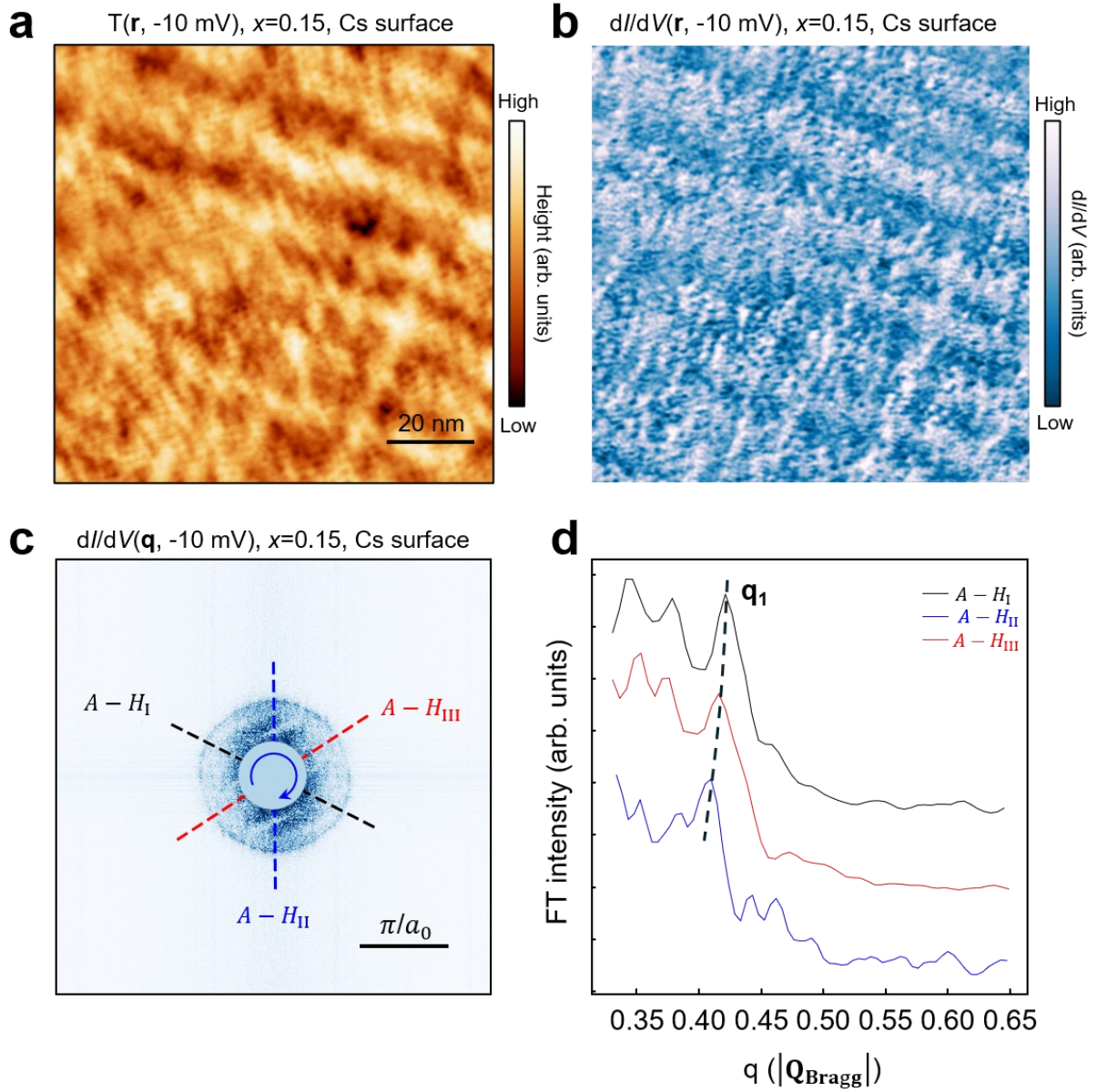
Supplementary Figure 11. Evolution of the superconducting gap upon Ti doping. Spatially-averaged dI/dV spectra obtained on the Sb surfaces of the CsV_3Sb_5 (black curve) and $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ samples ($x=0.00, 0.05, 0.15$ and 0.27 , corresponding to red, blue, and green curves, respectively), showing a transition from V-shape to U-shape symmetry through Ti substitution.



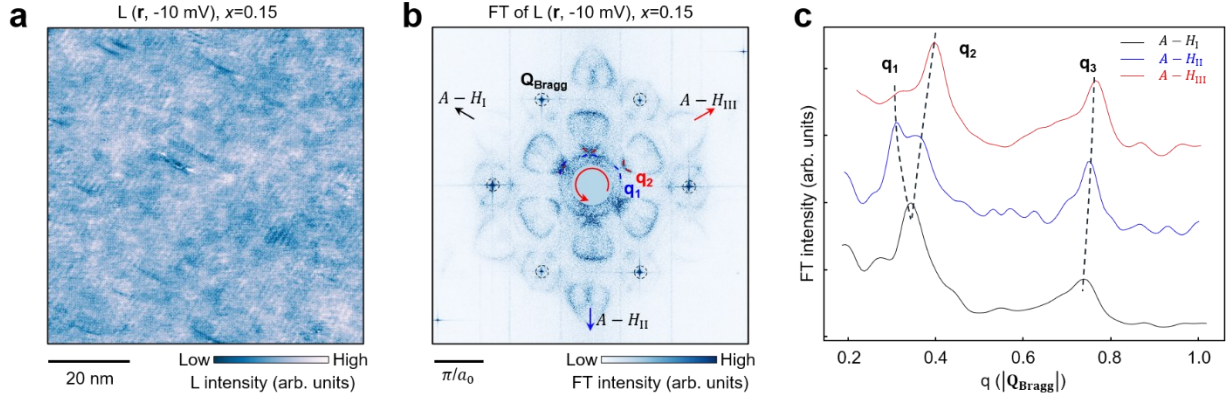
Supplementary Figure 12. Lattice structure symmetry analysis. **a**, Fourier-transformed topography (same as Fig. 1e), showing the Bragg peaks Q_A , Q_B , and Q_C . **b**, Lengths of the Bragg vectors Q_A , Q_B , and Q_C . The peaks are fitted with Gaussian function. The unit of the length represents 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.



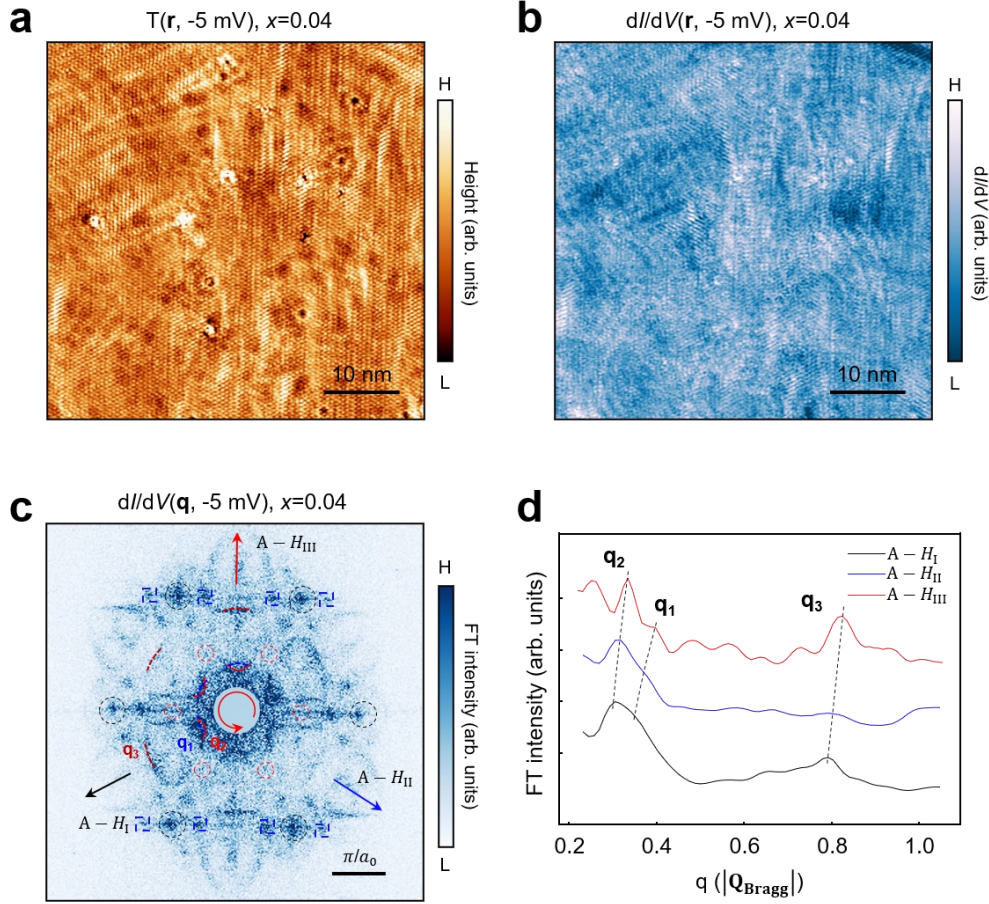
Supplementary Figure 13. Dominant impurities. **a**, STM topography of the Sb surface, revealing circular Sb vacancies and underlying Ti dopants as the dominant impurities. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern arising from these impurities.



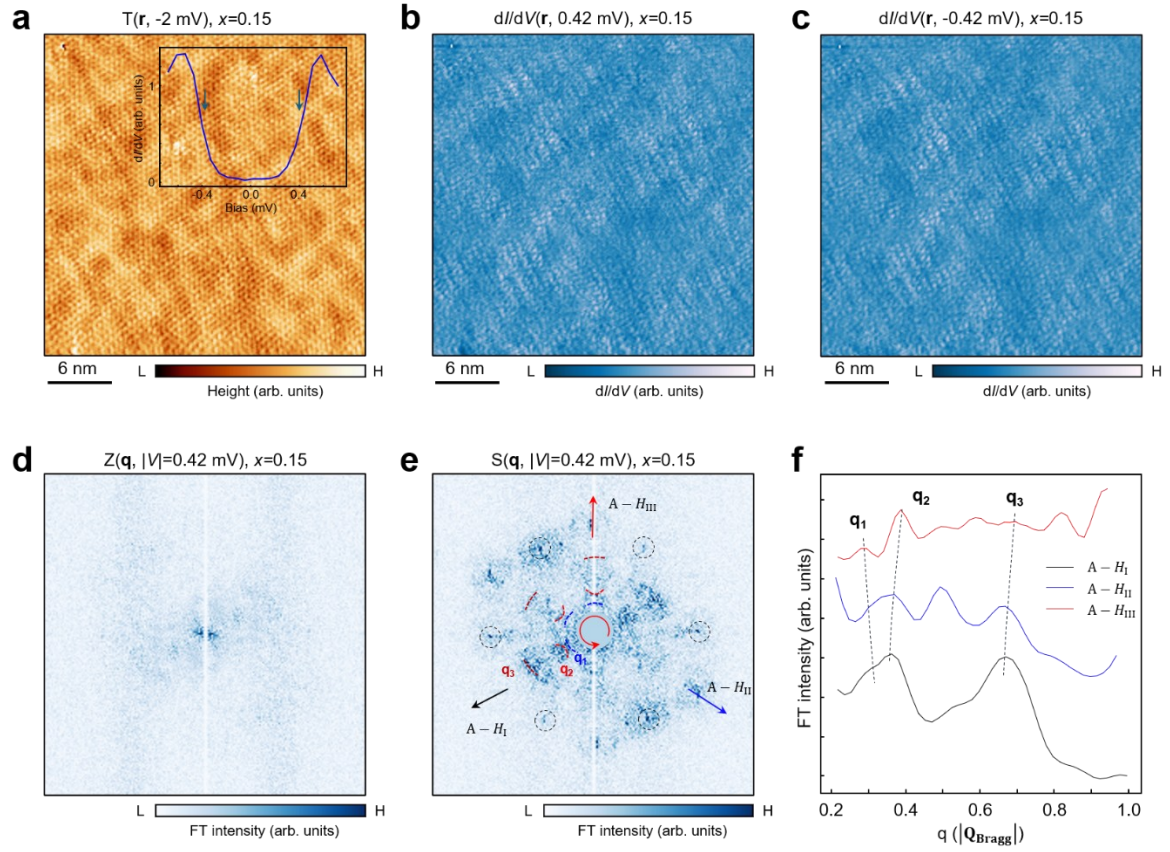
Supplementary Figure 14. Rotational and mirror symmetry breaking on the Cs surface. **a**, STM topography of the Cs surface. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern. **c**, FT of (b), showing asymmetric $\mathbf{q}_1$ along different directions. **d**, Line profiles 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 $\mathbf{q}_1$, which indicate the chirality of $q_1^{H_m}$ ($i = 1, 2, 3; m = \text{I, II, III}$). The different lengths of $\mathbf{q}_1$ are guided by dotted curves.



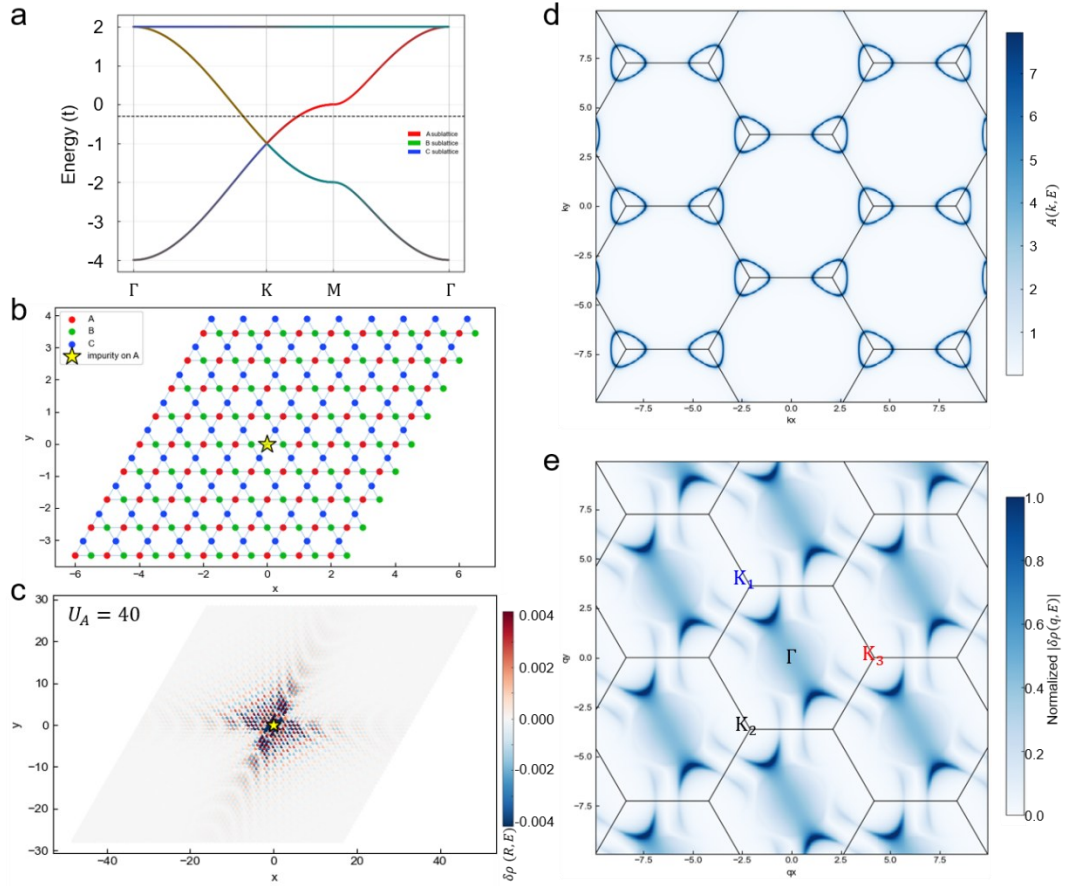
Supplementary Figure 15. Rotational and mirror symmetry breaking using Feenstra-normalized conductance map. **a**, Feenstra normalized conductance map of the data in Fig. 1f. **b**, FT of (a), showing rotational and mirror symmetry breaking QPI pattern. **c**, Line profiles extracted from (b) along the $A - H_I$, $A - H_{II}$, and $A - H_{III}$ directions, respectively, revealing different length of the $\mathbf{q}_1$, $\mathbf{q}_2$, 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.



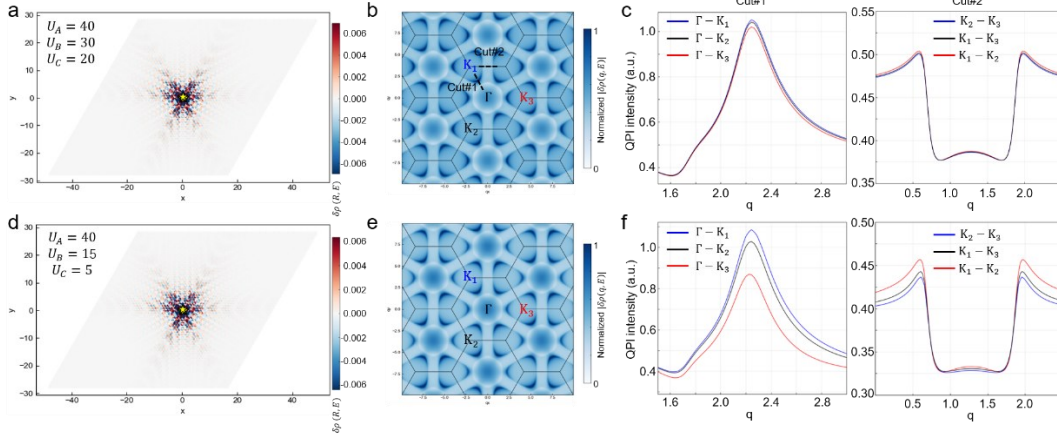
Supplementary Figure 16. Rotational and mirror symmetries breaking on a $x=0.04$ sample. **a**, STM topography of the Sb surface of $\text{CsV}_{3-x}\text{Ti}_x\text{Sb}_5$ ($x=0.04$), showing the presence of charge orders. $V_{\text{bias}} = -5$ mV, $I = 200$ pA, $V_{\text{lock-in}} = 0.2$ mV. **b**, dI/dV map of the same region as (a), showing the real-space QPI pattern. **c**, FT of (b), showing asymmetric $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ 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 $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$, which indicate the chirality of $q_i^{H_m}$ ($i = 1, 2, 3; m = \text{I, II, III}$). The different lengths of $\mathbf{q}_1$, $\mathbf{q}_2$, and $\mathbf{q}_3$ are guided by dotted curves.



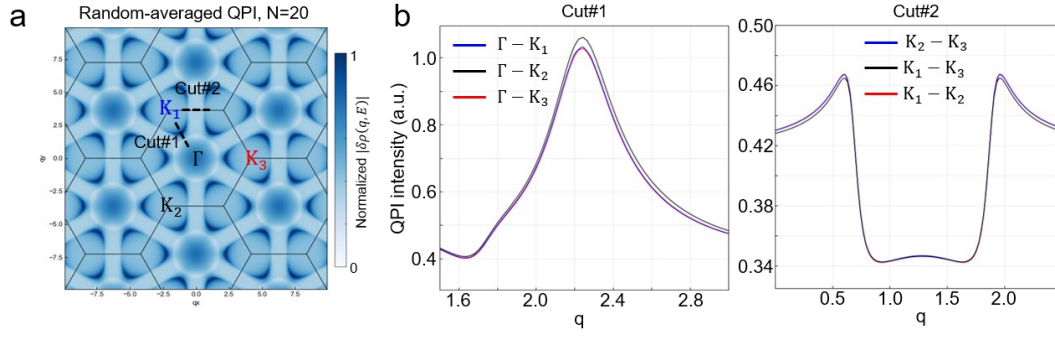
Supplementary Figure 17. Robust rotational and mirror symmetries breaking on Bogoliubov QPI at CsV_{3-x}Ti_xSb₅ (x=0.15) sample #3. **a**, STM topography of the Sb surface of CsV_{3-x}Ti_xSb₅ (x=0.15) sample #3. $V_{bias} = -2$ mV, $I = 200$ pA, $V_{lock-in} = 0.1$ mV. The inset shows the superconducting 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 (c) 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.



Supplementary Figure 18. 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 $U_A/t = 40$.



Supplementary Figure 19. T-matrix simulation of a three-sublattice anisotropic impurity configuration on a kagome lattice. **a**, Impurity-induced real-space LDOS modulation, $\delta\rho(R, E)$, 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, $|\delta\rho(q, E)|$, 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, $\delta\rho(R, E)$, 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, $|\delta\rho(q, E)|$, 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).



Supplementary Figure 20. 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).

	$\mathbf{q}_1$	$\mathbf{q}_2$	$\mathbf{q}_3$
$\overline{\Delta q_s}$	0.0140	0.0214	0.0152
$\overline{v_s}$	2302.05	670.80	979.86
$\Delta E = \overline{\Delta q_s} \cdot \overline{v_s}$	32.28	14.36	14.90
T_{eff}	374.6	166.7	172.9

Supplementary Table 1. Estimation of the effective temperature scale for the chiral nematic Fermi liquid state. The differences between q_i^m (in units of $|\mathbf{Q}_{\text{Bragg}}|$) at the Fermi level and the linear slope v_i (in units of meV/ $|\mathbf{Q}_{\text{Bragg}}|$) are averaged over the three high-symmetry directions. The energy scale of the distortion is estimated as $\Delta E = \overline{\Delta q_s} \cdot \overline{v_s}$ (in units of meV). The corresponding effective temperature scale is obtained from $T = \Delta E/k_B$ (in units of K), where k_B is the Boltzmann constant.

	$\mathbf{v}_i^{\text{I}}$	$\mathbf{v}_i^{\text{II}}$	$\mathbf{v}_i^{\text{III}}$	$\mathbf{v}_i^{\text{DFT}}$	R^{I}	R^{II}	R^{III}
$\mathbf{q}_1$	2291.92	2553.65	2060.59	3037.36	1.33	1.19	1.47
$\mathbf{q}_2$	824.58	646.32	541.50	1263.32	1.53	1.95	2.33
$\mathbf{q}_3$	1113.01	972.99	853.57	1607.08	1.45	1.65	1.88

Supplementary Table 2. Estimation of the effective mass renormalization ratio. The linear slopes v_i^m (in units of meV/ $|\mathbf{Q}_{\text{Bragg}}|$) are extracted by linear fits to the q-dispersions along the three high-symmetry directions. The effective mass renormalization ratios R^m are estimated as $\frac{1}{v_i^m} / \frac{1}{v_{\text{DFT}}}$.

Supplementary References

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