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Quasiparticle interference of the Dirac Line Node Material ZrSiS

3D Dirac line node semimetals [1] are emerging as classes of materials which promise topological protection of electronic states within their bulk. In these materials, conductance and valence bands meet along closed path in momentum space, forming a gapless linear Dirac dispersion at low energy. Such band structures are predicted to give rise to exotic states at the materials' surfaces including Dirac line node arcs [2] and spin vortex rings [3]. However, in many nodal line semimetals, the line node itself is located above the Fermi energy, making it inherently inaccessible to be resolved by experimental techniques such as angle-resolved photoemission spectroscopy (ARPES) [4, 5]. In addition, bulk characterization methods such as transport measurements [6, 7] give access only to bulk-averaged electronic properties, providing limited insight into quasiparticle scattering and interference at the atomic-level.

Here we demonstrate the impact of single-atomic defects on quasiparticle interference (QPI) in the Dirac line node semimetal zirconium silicon sulphide (ZrSiS). Differential conductance mapping of the material's surface at 4.5K allows us to resolve the characteristic quasiparticle scattering patterns and to identify the dominant scattering vectors which give insight into pseudospin selection rules.

Supported by first-principles numerical modelling, we determine Dirac line node position at ~100meV within the conduction band and a Fermi velocity of $\hbar v_F$ = (2.65±0.10) eV Å (in Γ-M direction and above ~300 meV).

More importantly, whilst we find that valley-pseudospin is preserved for small excitations around the Dirac line-node, certain atomic defect centres in the material can break the line-node protecting glide-mirror symmetry, giving rise to effective scattering between states with opposite valley pseudospin deep inside valence and conduction band.

Our study thus further motivates the investigation of quasiparticle interference at the atomic level in topological materials, whilst defect engineering may ultimately aid the development of lower-power electronics via dissipationless electronic transport in the future.

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Figures

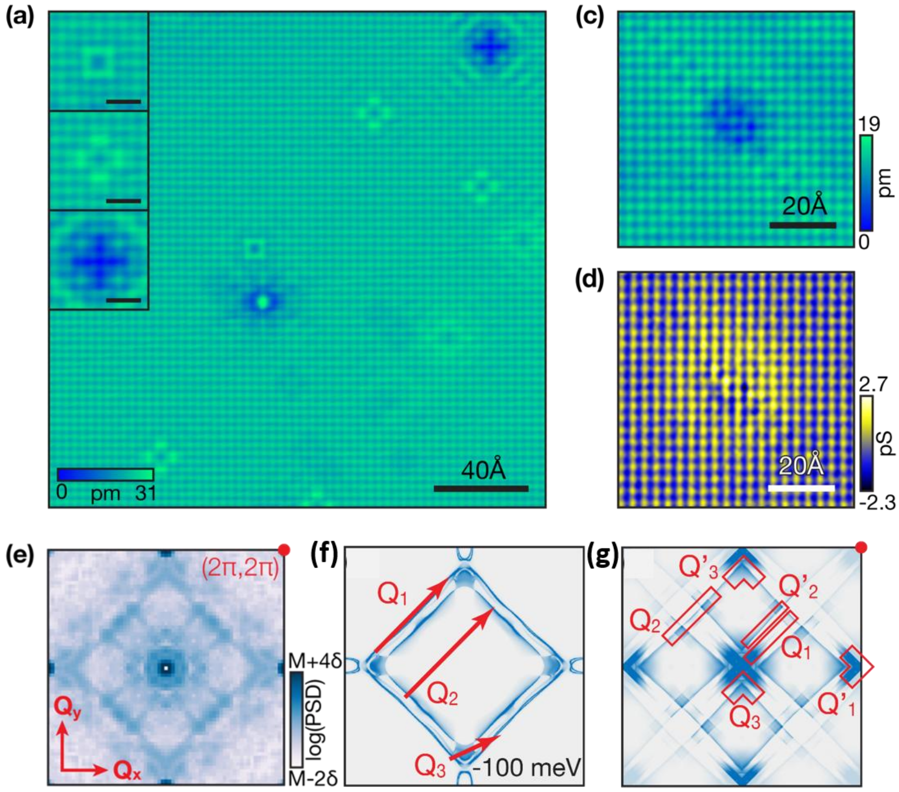

Figure 1: Quasiparticle interference of ZrSiS. (a) Low-temperature scanning tunnelling microscopy topography image of the cleaved ZrSiS surface, showing a number of single-atomic defects. Characteristic modulations in the local density of states arise from interference of scattered quasiparticles. (c) Close-up of a single point defect in topography as well as (d) a corresponding differential conductance map at a sample bias of -100mV. (e) 2D FFT of the same area, showing the approximately square shaped Fermi surface. (f) The observed quasiparticle interference pattern is a direct consequence of the material's surface spectral weight with strongly nested scattering vectors Q_i across the two concentric squares reflecting the Dirac dispersion at energies away from the line node. (g) Modelled quasiparticle interference pattern, calculated using the T-matrix approach, showing good agreement with the experimental data in (e).