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Charge density wave induced nodal lines in $LaTe_3$

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$LaTe_3$ is a non-centrosymmetric material with time reversal symmetry, where the charge density wave is hosted by the Te bilayers. Here, we show that $LaTe_3$ hosts a Kramers nodal line—a twofold degenerate nodal line connecting time reversal-invariant momenta. We use angle-resolved photoemission spectroscopy, density functional theory with an experimentally reported modulated structure, effective band structures calculated by band unfolding, and symmetry arguments to reveal the Kramers nodal line. Furthermore, calculations confirm that the nodal line imposes gapless crossings between the bilayer-split charge density wave-induced shadow bands and the main bands. In excellent agreement with the calculations, spectroscopic data confirm the presence of the Kramers nodal line and show that the crossings traverse the Fermi level. Furthermore, spinless nodal lines—completely gapped out by spin-orbit coupling—are formed by the linear crossings of the shadow and main bands with a high Fermi velocity.

Recent years have witnessed rapid development in the understanding of the physics of cooperative charge density wave (CDW) electronic state[1–12]. In particular, the interplay of the CDW electronic state with the non-trivial topological phases provides an interesting platform for the discovery of novel quasiparticles such as, axion insulator[3,13], quantum spin-Hall insulator[14], fractional Chern insulator states[15] and manipulation of topologically protected states[16,17]. CDW can drive topological phase transitions by modifying the symmetry of the lattice, such as breaking the inversion symmetry[18]. Interesting topological phases are frequently found in non-centrosymmetric materials, such as nodal chain fermions[19], Dirac and Weyl fermions[20–22], hourglass fermions protected by glide reflection[23], Kramers Weyl semimetal (KWS)[24] and recently predicted Kramers nodal line (KNL) metal[25]. KNLs differ from the Weyl nodal lines because they join two time reversal invariant momenta (TRIM) points and should appear in all achiral non-centrosymmetric time reversal symmetry (TRS) preserving systems[25]. For the subclass of nonsymmorphic symmetry, KNLs emerge from the Γ points. Unlike the previously known nodal lines manifested by band inversion[26], the KNLs are robust under spin-orbit coupling (SOC) unless the protecting lattice symmetries such as TRS, mirror, or roto-inversion symmetries are broken. KNL fermions have been predicted to exhibit physical properties such as quantized optical conductivity[25]. However, in this emerging field, to the best of our knowledge, the experimental evidence of KNL is limited to the work by Shang et al.[27] who reported that transition metal ruthenium silicides belong to this class and exhibit unconventional superconductivity based on muon spin spectroscopy and density functional theory (DFT).

In recent years, multiple fascinating findings in $LaTe_3$[1,4,7,28–30]—a member of the RTe_3 (R represents a rare earth element) family with highest CDW transition temperature of 670 K[31,32]—have rekindled the

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