Emergence of Kondo Lattice Behavior

The emergence of a sharp quasiparticle peak and d-electron heavy fermion states, along with the potential role of Kondo interaction, provide insights into the interplay between Kondo hybridization and long-range magnetic order in FeTe.

FeTe is a special material due to its strong electron correlation, which might be the strongest among the iron-based superconductors. FeTe holds a unique magnetic ground state, which is bicollinear antiferromagnetism with a large magnetic moment, indicating its local nature of magnetism. Additionally, FeTe exhibits heavy effective mass and strong spin-electron interaction, making it an ideal candidate for studying *d*-electron heavy fermion states and their potential connection to Kondo interaction and magnetic order. The temperature dependent spectroscopic measurements uncovers how FeTe acts as a Fermi liquid at low temperature transitions between different states as the temperature increases and thus open up new possibilities for understanding unusual behaviors in materials and could lead to the development of advanced technologies.

Soonsang Huh and Changyoung Kim (Seoul National University, Korea) utilized several experimental methods to investigate the electronic and magnetic properties of FeTe. Each contributed to a comprehensive understanding of these properties and offered valuable insights into the unique behavior of FeTe and the emergence of Kondo lattice behavior.

Angle-resolved photoemission spectroscopy (ARPES) is one of the key methods used to directly observe the key features of heavy fermion behavior in FeTe, specifically the emergence of a sharp quasiparticle peak near the Γ point and its strong temperature dependence. This technique provided spectroscopic evidence for the Kondo lattice behavior in FeTe. Furthermore, the photon energy-dependent ARPES data provided further insights into the origin of the observed electron band of FeTe, which was clearly visible at 11 eV and displayed strong k_z dispersion. As the photon energy increased, the band shifted to the higher binding energy, and its energy scale became more than 0.5 eV (**Fig. 1**). Considering FeTe is in the strongly correlated limit, a bandwidth of 0.5 eV far surpasses that of Fe 3*d* bands. In addition, the photoionization cross-section of the Te 5*p* orbital is much larger than that of the Fe 3*d* orbital at 11 eV. Thus, the band observed at 11 eV most likely can be attributed to the Te p_z orbital. The photon energy-dependent ARPES measurements were conducted at **TLS 21B1** (NSRRC). The results of this work provide valuable insights into the electronic structure and properties of FeTe, offering a multi-faceted view of the material's behavior at different energy scales.

In addition, ARPES measurements using a laser-based ARPES system equipped with a 10.897 eV laser and a time-of-flight analyzer provided direct spectroscopic evidence for the emergence of a sharp quasiparticle peak near the Γ point and exhibited strong temperature dependence in FeTe. This observation indicated the presence of Kondo lattice behavior, which was attributed to the hybridization between localized Fe 3d_{xy} and itinerant Te 5p_z orbitals. Additionally, the ARPES measurements revealed the orbital characteristics and Kondo hybridization, offering crucial insights into the electronic band structure and Fermi surface of FeTe (**Fig. 2**, see next page).

In addition to ARPES, scanning tunneling spectroscopy (STS) measurements provided further support for Kondo hybridization in FeTe, displaying a Fano-type line shape and narrow hybridization gap. The transport measurements revealed a dramatic change in resistivity at the Néel temperature, indicating insulating behavior above this temperature and metallic behavior below it. Additionally, density functional theory (DFT) calculations supported the observed Kondo lattice behavior and its role in determining the exotic physical and magnetic properties of FeTe. These

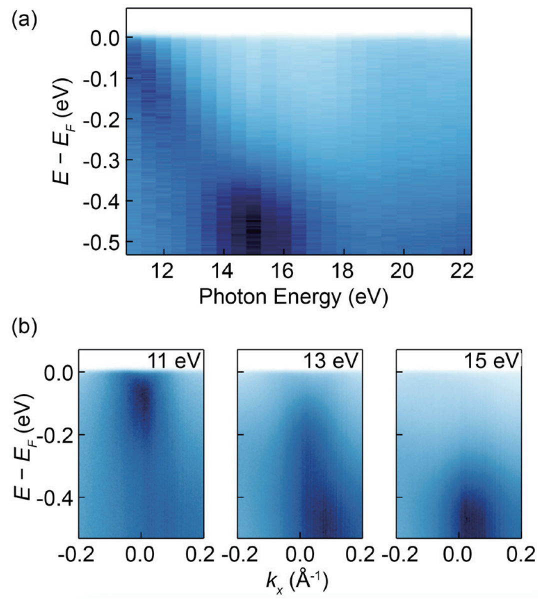

Fig. 1: Photon energy-dependent electronic structure. (a) Photon energy-dependent electronic structure near the Γ point. (b) Photon energy-dependent high symmetry cuts along the Γ-X direction, obtained using 11, 13, 15 eV photon. [Reproduced from Ref. 1]

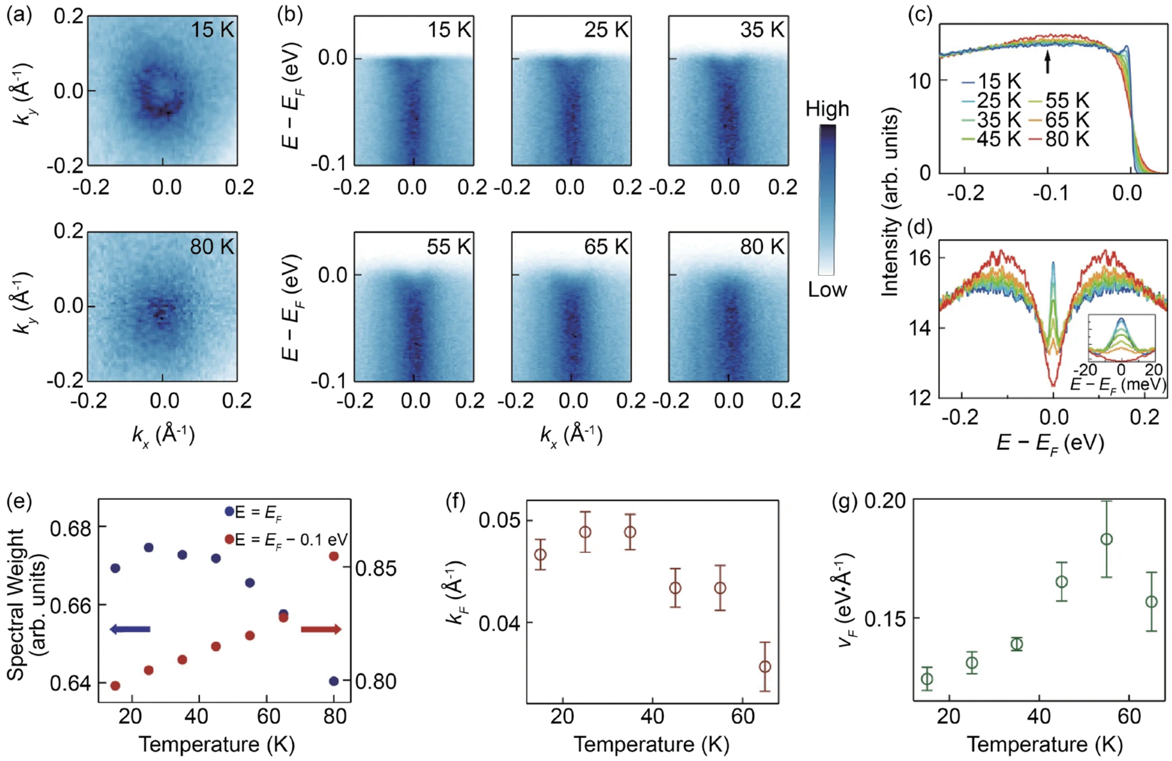

Fig. 2: (a) Fermi surface maps from high resolution laser ARPES measurements, obtained at 15 and 80 K. (b) Temperature dependent high symmetry cuts along the Γ'-X' direction. ARPES data were taken with 11 eV photons. (c) Energy distribution curves (EDCs) integrated within a certain momentum range ($k_x^2 + k_y^2 < (0.15$ Å$^{-1})^2$). The EDCs are normalized with the integrated intensity from an energy window of −0.25 eV < −0.2 eV. (d) Symmetrized EDCs of (c). Inset: enlarged view of EDCs near the Fermi level. (e) Temperature-dependent spectral weight at E = E_F and E = E_F − 0.1 eV. (f,g) Temperature-dependent Fermi momentum (k_F) and Fermi velocity (v_F), respectively, obtained from momentum distribution curve analysis. [Reproduced from Ref. 1]

combined experimental and theoretical approaches provide a comprehensive understanding of the electronic and magnetic properties of FeTe, highlighting the significance of the Kondo effect and its impact on the material's behavior.

This work provides a comprehensive understanding of the electronic and magnetic properties of FeTe, a material that has been the subject of intense research because of its unique properties and potential applications in superconductivity and spintronics. The study combines various experimental techniques, including ARPES, STS, and transport measurements, to reveal the interplay between Kondo hybridization and long-range magnetic order in FeTe and provide evidence for the emergence of Kondo lattice behavior. The study also provides insights into the origin of the anomalous Hall effect and the role of band inversion and topology in the bulk electronic structure of FeTe, shedding light on the interplay between spin and electronic degrees of freedom in correlated *d*-electron multiorbital systems. Overall, the study highlights the significance of the Kondo effect and heavy fermion states in FeTe. This may have implications for the development of new materials with unique electronic and magnetic properties. (Reported by Ping-Hui Lin)

This report features the work of Soonsang Huh, Changyoung Kim and their collaborators published in Nat. Comm. ***14****, 4145 (2023).*

TLS 21B1 Angle-resolved UPS

- ARPES
- Kondo Lattice Behavior, FeTe, ARPES, Heavy Fermion

Reference

1. Y. Kim, M.-S. Kim, D. Kim, M. Kim, M. Kim, C.-M. Cheng, J. Choi, S. Jung, D. Lu, J. H. Kim, S. Cho, D. Song, D. Oh, L. Yu, Y. J. Choi, H.-D. Kim, J. H. Han, Y. Jo, J. H. Shim, J. Seo, S. Huh, C. Kim, Nat. Comm. **14**, 4145 (2023).