the spin excitations likely reflect the shifting of the FBs away from E_F, both below and above E_F.[1]

Finally, the authors discuss that while their bare DFT electronic structure calculations do not accurately reproduce the observed bands below E_F, but when the necessary correlation corrections reconciles the discrepancies in the FB position at a qualitative level. This confirms the potential mechanism for the involvement of the kagome FBs in the formation of the CDW electronic order. Furthermore, since the chemical potential of $CsCr_3Sb_5$ is close to the kagome FBs, it is conceivable that their presence drives an electronic order that pushes the FBs away from the E_F, as observed in experiments. With hydrostatic pressure, this electronic CDW order can get suppressed and leave residual density of states from the FBs near E_F to experience the quantum fluctuations expected near a quantum critical point and potentially enable superconductivity. The authors conclude that the flat band in $CsCr_3Sb_5$ is clearly participates in the low-temperature order, as is evident from its shift away from E_F and its coupling with spin excitations.[1] (Reported by Ashish Chainani)

*This report features the work of Di-Jing Huang, Qimiao Si, Ming Yi, Pengcheng Dai and their collaborators published in Nat. Commun. **16**, 7573 (2025).*

TPS 41A Soft X-ray Scattering

- RIXS
- Materials Science, Condensed-matter Physics

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How Antiferromagnetism Shapes Superconductivity in Cuprate Materials

Their remarkable work links hidden magnetism to the birth of superconductivity in complex quantum materials.

Superconductivity in cuprates has remained a central challenge for more than four decades. Despite the discovery of numerous competing and intertwined phases, one of the most robust and universal features of the cuprate phase diagram is the dome-shaped T_C that arises near the boundary of antiferromagnetic (AF) order. This proximity has long suggested that AF spin fluctuations may serve as the pairing mechanism for superconductivity. Theoretical studies have explained the unconventional d-wave pairing symmetry within this framework, while angle-resolved photoemission spectroscopy (ARPES) has provided direct experimental access to quasiparticles and their many-body renormalization effects. However, determining how AF spin fluctuations specifically affect electronic states and promote superconductivity remains challenging due to strong correlations and the complexity of the cuprate phase diagram.

In the presence of long-range AF order at low electron doping, a superlattice potential folds the electronic bands and reconstructs the Fermi surface from a large hole-like cylinder into smaller electron and hole pockets. While this folding is well understood within mean-field descriptions of long-range AF order, remnants of reconstructed pockets have also been observed in the superconducting regime beyond the long-range AF phase boundary. These observations suggest a role for short-range AF fluctuations or other ordering phenomena. Further complicating the interpretation, ARPES studies have reported the simultaneous presence of both folded AF bands and unfolded pristine bands, indicating strong electron correlations and challenging conventional models.

Transport measurements have provided further evidence linking superconductivity to one of the AF-induced Fermi pockets. Magnetoresistance and quantum oscillation experiments on electron-doped cuprates such as $Nd_{2-x}Ce_xCuO_4{\pm}\delta$ have shown that hole-pocket contributions to conductivity occur only within the superconducting doping range. However, because these measurements require strong magnetic fields, it remains unclear whether the hole pocket is intrinsically associated with superconductivity under ambient conditions or if it is stabilized by field-enhanced AF order.

To resolve this issue, Changyoung Kim and his team at Seoul National University, Korea, combine ARPES and zero-field muon spin rotation/relaxation (μSR) measurements on the electron-doped cuprate $Pr_{1-x}LaCe_xCuO_4{\pm}\delta$ (PLCCO). This work is complemented by Hubbard-model calculations using cluster perturbation theory. Doping-dependent ARPES measurements were conducted at the **TPS 39A** nanoARPES beamline, focusing on the low-energy quasiparticle states along the nodal direction (nodal band) after removing the Fermi–Dirac cutoff, as shown in **Fig. 1**. The most underdoped non-superconducting sample (n ≈ 0.06) shows a clear energy gap that gradually closes with increasing electron doping. Within a mean-field framework, this gap originates from quasiparticle band splitting induced by effective AF scattering with Q = (π, π), and its closure reflects the weakening of the AF superlattice potential.

Although AF band folding is expected, the folded branch is barely visible in raw spectra due to weak matrix-element effects. In heavily underdoped samples (n ≈ 0.06 and 0.11), the shadow AF branch becomes discernible through stacked and normalized energy distribution curves, revealing a flattened band top and back-bending behavior centered at the AF zone boundary. As doping increases, the AF branch becomes diffuse and ill-defined, accompanied by spectral broadening and enhanced in-gap spectral weight. This enhancement is attributed to the growth of unfolded pristine states. The simultaneous presence of folded AF features and in-gap intensity indicates a superposed Fermi surface consisting of AF-derived pockets and a large pristine Fermi surface, reflecting many-body effects that extend beyond the conventional mean-field description. In addition to the phenomenological analysis, the researchers conducted a function-fit analysis on the nodal band spectra

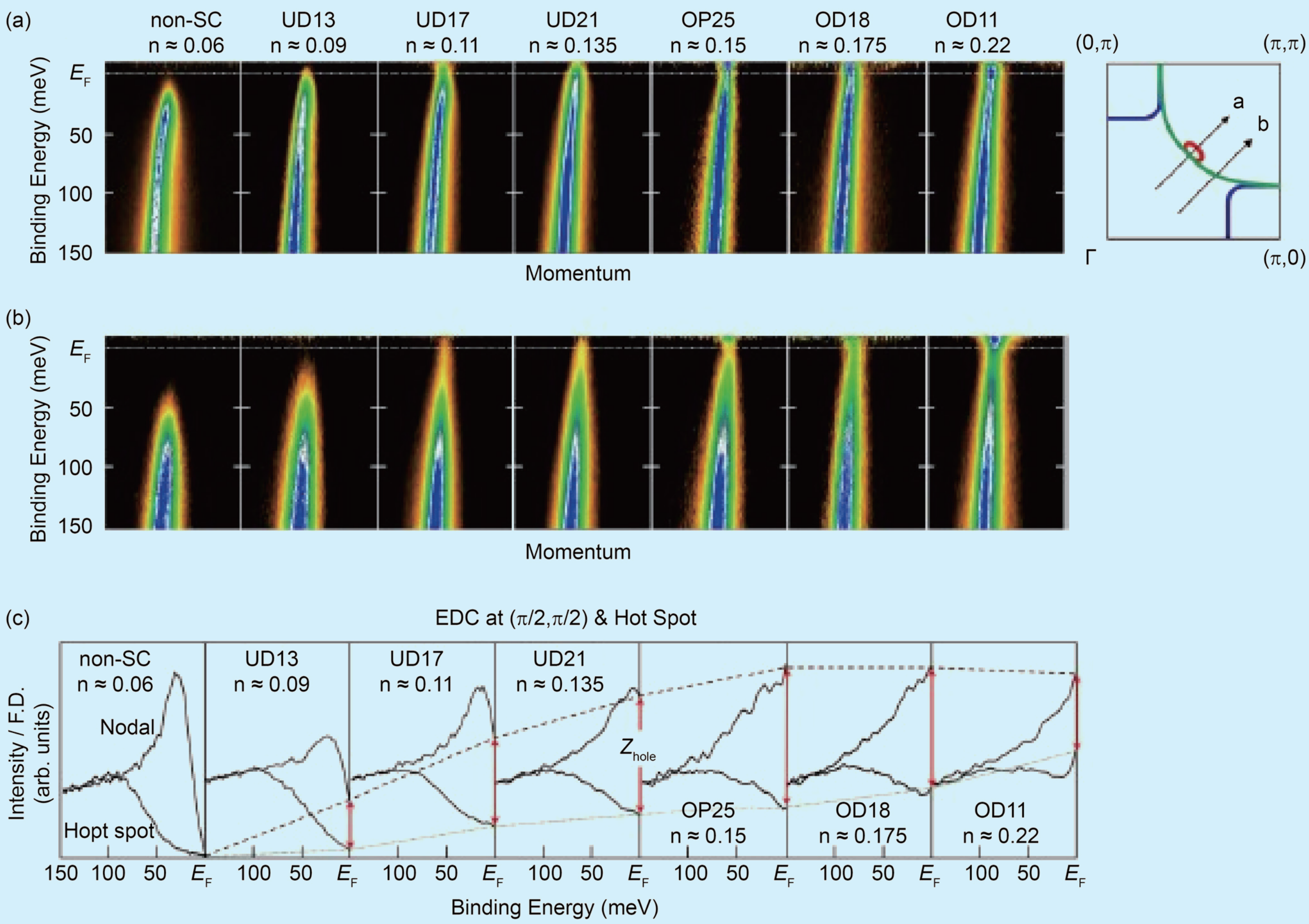

Fig. 1: Doping evolution of the nodal band in PLCCO. ARPES spectra collected along the nodal line. ARPES spectra collected along the hot spot. Energy Distribution Curves (EDCs) at (π/2, π/2) and the hot-spot point for various doping levels. Black dashed and green dotted lines indicate the zero-energy intensity of each EDC. [Reproduced from Ref. 1]

without involving the hot-spot spectra. The function fitting also allows them to determine the AF peak position even in the overdoping region where the peak shape is ambiguous due to strong in-gap pristine intensity. They reported the unconventional reconstruction of the Fermi surface, characterized by the coexisting L-circle and pockets, originates from strong correlations instead of static disorder.

Their high-resolution ARPES shows that the nodal quasiparticle spectrum contains both folded AF and unfolded pristine components, consistent with numerical simulations. By monitoring the doping evolution of the folded AF branch, the study finds that superconductivity appears when the folded hole band first crosses the Fermi energy within a short-range AF ground state, near a possible quantum critical point separating static and dynamic AF order. Notably, the zero-energy spectral weight of the hole band scales with T_C, while the energy difference between the band top and the Fermi level is inversely correlated with T_C. These findings indicate that an incipient hole band, driven by electron–spin fluctuation coupling, plays a central role in the emergence of superconductivity in electron-doped cuprates. (Reported by Cheng-Maw Cheng)

This report features the work of Changyoung Kim and his collaborators published in Nat. Commun. ***16****, 2764 (2025).*

TPS 39A Nanometer Angle-resolved Photoemission Spectroscopy (NanoARPES)
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- Materials Science, Condensed-matter Physics

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Spin-Valley Coupling Enhanced High-T_C Ferromagnetism in a Non-van der Waals Monolayer Cr_2Se_3 on Graphene

Metallic ferromagnetism with a record high Curie temperature (T_C ~225 K) originating from spontaneous spin-valley polarization is reported for a binary monolayer: Cr_2Se_3 on graphene.

Spin-valley coupled magnetic ordering is known to occur in layered van der Waals transition-metal dichalcogenides, but with ordering temperatures below 55 K. Recent theoretical studies predicted that non-van der Waals structures can also exhibit spin-valley polarization–induced semiconducting ferromagnetic (FM) ground states, but experimental confirmation was lacking. In an international collaboration between Japan, France, and Taiwan, researchers have now reported a record high Curie temperature (T_C ~ 225 K) metallic ferromagnetism arising from spontaneous spin-valley polarization in the non-van der Waals monolayer (ML) of the binary compound Cr_2Se_3 on graphene. Using angle-resolved photoemission spectroscopy (ARPES), X-ray absorption spectroscopy (XAS), X-ray magnetic circular dichroism (XMCD), and circular dichroism (CD) in ARPES, Chien-Wen Chuang (Tohoku University), Takafumi Sato (Tohoku University), Ashish Chainani (NSRRC) and their collaborators have demonstrated that ML Cr_2Se_3 on graphene exhibits spin-valley-coupled FM ordering.[1]

A recent first-principles calculation predicted that a combination of broken inversion symmetry, strong spin-orbit coupling, and magnetic exchange interaction with intrinsic out-of-plane magnetization in ML Cr_2Se_3 results in a spontaneous coupling of spin and valley polarization. This leads to a FM semiconductor with anomalous valley Hall effect.[2] However, there have been no experimental reports of spin-valley coupling in either bulk or ML Cr_2Se_3, or in any non-van der Waals material. Furthermore, there is no experimental evidence that magnetic ordering temperatures are enhanced or exceed 55 K due to spin-valley coupling.[3]

Cr_2Se_3 is a non-van der Waals material, and its ML consists of a quintuple set of Se-Cr-Se-Cr-Se atomic layers, as shown in **Fig. 1(a)**. The authors used molecular beam epitaxy to grow 1 to 3 MLs of Cr_2Se_3 on graphene. The reflection high-energy electron diffraction (RHEED) pattern of the fabricated film showed clear streaks associated with the 1 × 1 structure of Cr_2Se_3, besides the 1 × 1