

# Momentum-Resolved Low-Energy Electron Emission from Crystalline Graphite: From Direct Photoemission to Secondary Cascades and Doorway States

**Alessandra Bellissimo<sup>\*a,d</sup>, Maosheng Hao<sup>b</sup>, Florian Simperl<sup>c</sup>, Wolfgang S.M. Werner<sup>c</sup>, Péter Dombi<sup>d</sup>, Florian Libisch<sup>b</sup>, Iva Březinová<sup>b</sup>, and Joachim Burgdörfer<sup>b</sup>**

<sup>a</sup> Photonics Institute, TU Wien, Gußhausstraße 25-29/E387, Vienna, 1040, Austria

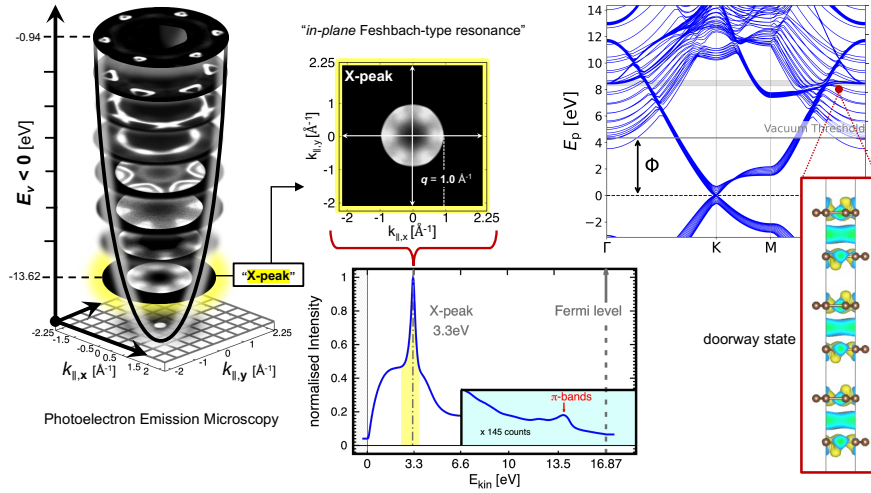
<sup>b</sup> Institute for Theoretical Physics, TU Wien, Wiedner Hauptstraße 8-10/E136, Vienna, 1040, Austria

<sup>c</sup> Institute of Applied Physics, TU Wien, Wiedner Hauptstraße 8-10/E134, Vienna, 1040, Austria

<sup>d</sup> HUN-REN Wigner Research Centre for Physics, Konkoly-Thege Miklós út 29-33, Budapest, 1121, Hungary

Low-energy secondary electrons (LE-SEs) are the final products of the energy-dissipation cascade initiated, for example, by ionising radiation. Despite their central role in electron-driven chemistry, imaging and nanofabrication, the mechanisms governing their generation, transport and escape from solids are not yet completely understood. Multiple inelastic scattering usually erases information on their electronic origin, producing broad, largely featureless secondary-electron spectra familiar from electron-emission measurements. Layered materials are a striking exception: their strongly anisotropic electronic structure can imprint pronounced energy- and momentum-dependent fingerprints even deep in this low-energy regime [1].

We employed high-resolution, momentum-resolved photoelectron emission microscopy (PEEM) to investigate electron emission from single-crystalline graphite across the transition from direct valence-band photoemission to final-state-dominated emission and LE-SEs generated by the inelastic cascade. Comparison with electronic-structure calculations disentangles contributions from occupied initial states, high-lying conduction-band states, and scattering-induced population and phonon-induced hybridisation of in-plane and interlayer final states.



**Figure 1.** (left to right) PEEM constant-energy contours across the valence band; momentum distribution and spectral position of the secondary-electron “X-peak”; 14-layer graphite band-structure calculations showing coupling of the in-plane resonance to the vacuum continuum; charge density of a representative doorway state [1].

Most strikingly, the characteristic low-energy “X-peak” [1-3] retains a pronounced momentum-space structure. Its momentum distribution identifies a quasi-bound, predominantly in-plane final-state resonance acting as an efficient electronic doorway for escape into vacuum. This demonstrates that, even deep within the slow secondary-electron regime, emission can be strongly shaped by the unoccupied electronic structure, with surface- and phonon-induced symmetry breaking enabling Feshbach-type resonances to couple to the vacuum continuum.

These results follow the photoemission pathway from direct photoelectron ejection through energy redistribution into cascade electrons to the formation of preferentially emitting secondary-electron doorway states, demonstrating how layered electronic structures influence and shape LE-SE generation and emission [1].

## References

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