Contribution ID: **57** Type: **Poster**

Charge-density-wave quantum critical point in 2H-TaSe2

Wednesday 7 January 2026 09:45 (30 minutes)

Superconductivity often emerges as a dome around a quantum critical point (QCP) where long- range order is suppressed to zero temperature, e.g., in high-temperature superconductors. However, the presence of a putative charge-density-wave (CDW) QCP and its impact on emerging superconductivity received increased scientific attention only after the discovery of CDW order in copper oxides. By now, it is known that various metallic transition-metal dichalcogenides feature emergent superconductivity when CDW order is suppressed, e.g., by pressure or intercalation and researchers are trying to understand the relevance of a CDW QCP for superconductivity in these systems.
Here, I will present our study of the CDW compound $2H$-$TaSe_2$. We used inelastic x-ray scattering (IXS) and x-ray diffraction (XRD) at ambient [1] and high pressures [2] up to 25 GPa to determine the CDW phase diagram and study its lattice dynamical properties. Our experimental results are complemented by $ab-initio$ lattice dynamical calculations based on density-functional perturbation theory. Results at ambient pressure provide first evidence for a full phonon softening at the CDW transition in $2H$-$TaSe_2$ and reveal a novel precursor region above the CDW transition temperature T_{CDW}, which is characterized by an overdamped phonon mode without long range order. Our high-pressure XRD defines the critical pressure $p_c \approx 20\,\mathrm{GPa}$ at which CDW order is fully suppressed. IXS identifies the presence of a CDW soft phonon mode at p_c which is strong evidence for a continuous nature of the CDW transition near zero temperature, and, thus, a CDW QCP. Calculations show that electron-phonon coupling in $2H$-$TaSe_2$ is mostly carried by the CDW soft phonon mode and can rationalize the reported superconducting transition temperatures at high pressures.

[1] Shen, X., Heid, R., Hott, R., Haghighirad, A.-A., Salzmann, B., dos Reis Cantarino, M., Monney, C., Said, A. H., Frachet, M., Murphy, B., Rossnagel, K., Rosenkranz, S. & Weber, F. Precursor region with full phonon softening above the charge-density-wave phase transition in 2H-TaSe2. Nat Commun 14, 7282, doi:10.1038/s41467-023-43094-5 (2023).
[2] Tymoshenko, Y., Haghighirad, A.-A., Heid, R., Lacmann, T., Ivashko, A., Merritt, A., Shen, X., Merz, M., Garbarino, G., Paolasini, L., Bosak, A., Diekmann, F. K., Rossnagel, K., Rosenkranz, S., Said, A. H. & Weber, F. Charge-density-wave quantum critical point under pressure in 2H-TaSe2. Communications Physics 8, 352, doi:10.1038/s42005-025-02254-3 (2025).

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Session Classification: Wednesday Coffee Break & Poster

Track Classification: Categories: van der Waals experimental