

Probing the Planckian scattering rate of the strange metal PdCrO₂

Juan L. Santana González¹, Adrien Gourgout¹, Mohamed Oudah²,
David Graf³, Benoît Fauqué⁴, Alannah Hallas², Gaël Grissonnanche¹

¹Laboratoire des Solides Irradiés, École Polytechnique, Palaiseau, France

²University of British Columbia, Vancouver, ON, Canada

³National High Magnetic Fields Laboratory, Tallahassee, FL, USA

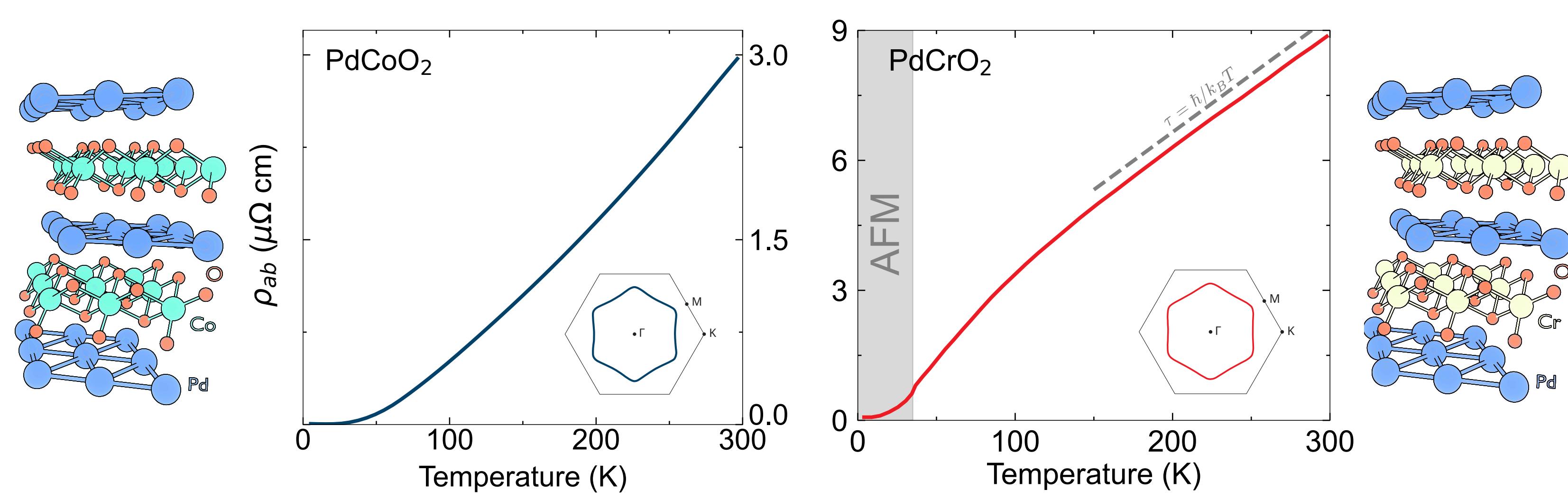
⁴Laboratoire de Physique et d'Étude des Matériaux, ESPCI, Paris, France

Question^{1,2,3,4,5}

Does the Planckian limit emerge from antiferromagnetic fluctuations?

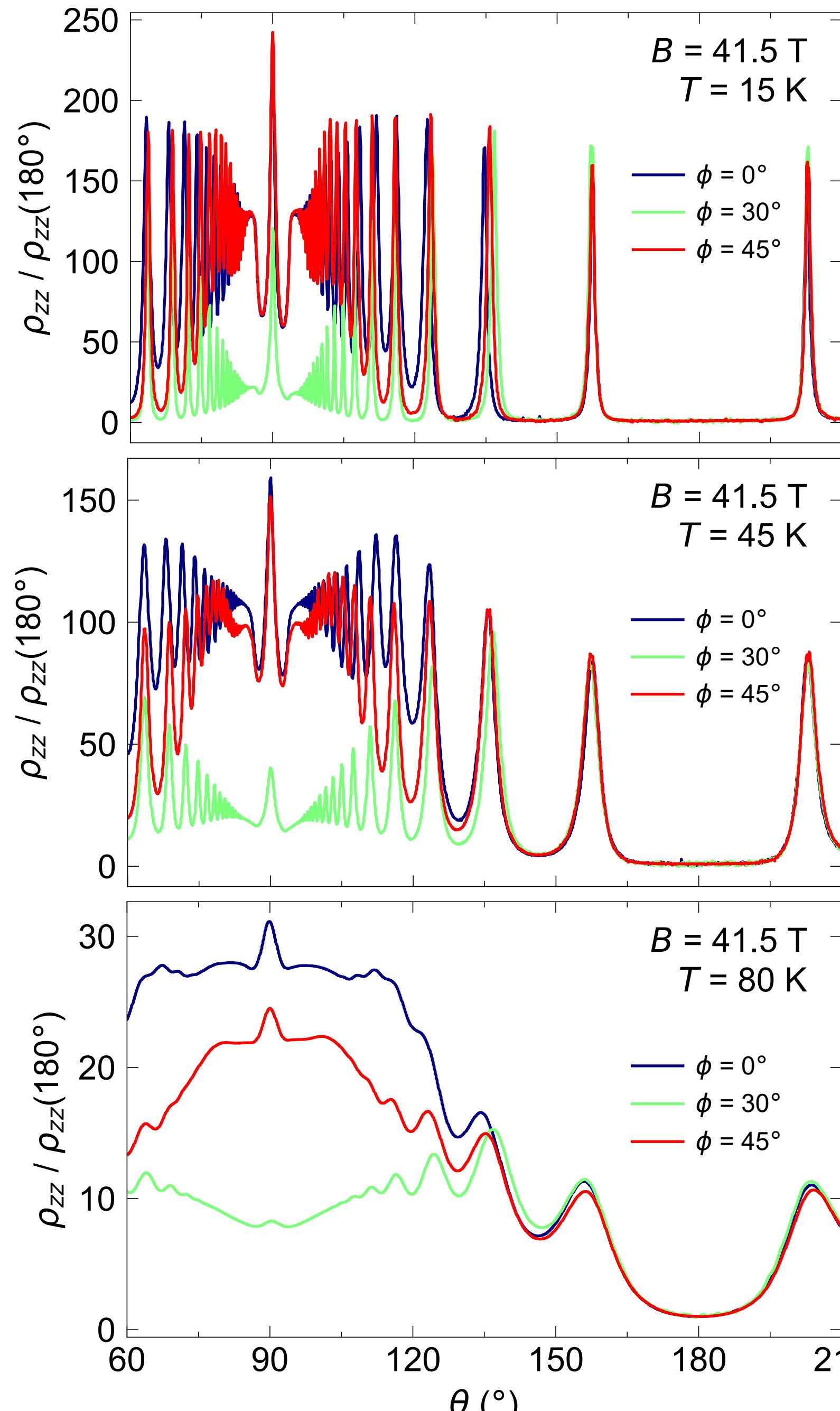
PdCrO₂ is a frustrated antiferromagnet (AFM) with a Neel Temperature of 37.5K. Above such temperature, its resistivity shows T-linear dependence, typical of strange metals. This behaviour has been recently associated to the Planckian limit¹, where the scattering time of electrons follows $\tau = \hbar/k_B T$. At high temperature, usually electron-phonon scattering is responsible for T-linear resistivity, but in PdCrO₂, an isostructural non-magnetic compound, the resistivity is not linear in this range of temperature, which suggests that T-linear resistivity must come from AFM fluctuations above T_{Neel}. Besides, the weak electron-phonon coupling in this family of materials strengthens this point.

To investigate this, we performed Angle-Dependent MagnetoResistance (ADMR) measurements at high magnetic fields in both PdCoO₂ and PdCrO₂. The objective is to directly extract from ADMR the Fermi surface and the scattering rate using semiclassical transport modeling (as successfully performed in strange metal cuprates⁵), and compare the scattering rates for both materials. Above the AFM phase, PdCoO₂ and PdCrO₂ have identical Fermi surfaces, therefore, we expect to find that the scattering rate is only Planckian in PdCrO₂. In addition, the ADMR should provide essential information on the momentum dependence of the scattering time for both materials, that will help us understand the origin of the Planckian limit in strange metals.

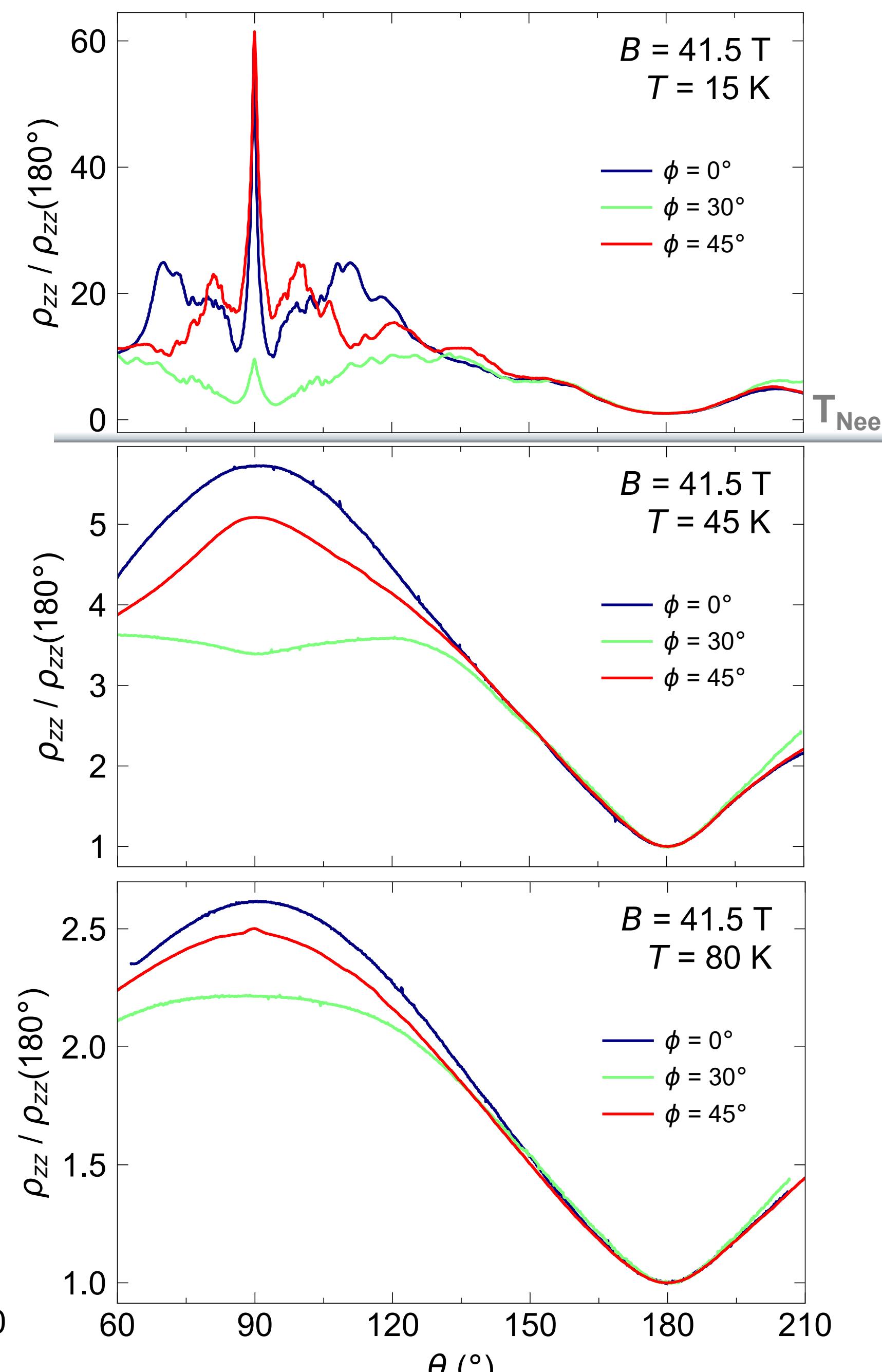


Results

PdCoO₂



PdCrO₂



Comments

In order to probe the ADMR of PdCrO₂ and PdCoO₂, we measured their c-axis resistivity ρ_{zz} at the National High Magnetic Fields Laboratory (NHMFL), Tallahassee, Florida under extreme magnetic fields of 41.5T. The samples were rotated inside the magnetic field at 13 different temperatures, with θ defined as the angle between the c-axis (z-axis) and the field orientation. The experiment is repeated for the different in-plane ϕ angles (azimuthal angle). Due to the three-fold symmetry of the crystal, these three in-plane directions are enough to capture the shape of the Fermi Surface.

Approach

Angle-Dependent MagnetoResistance

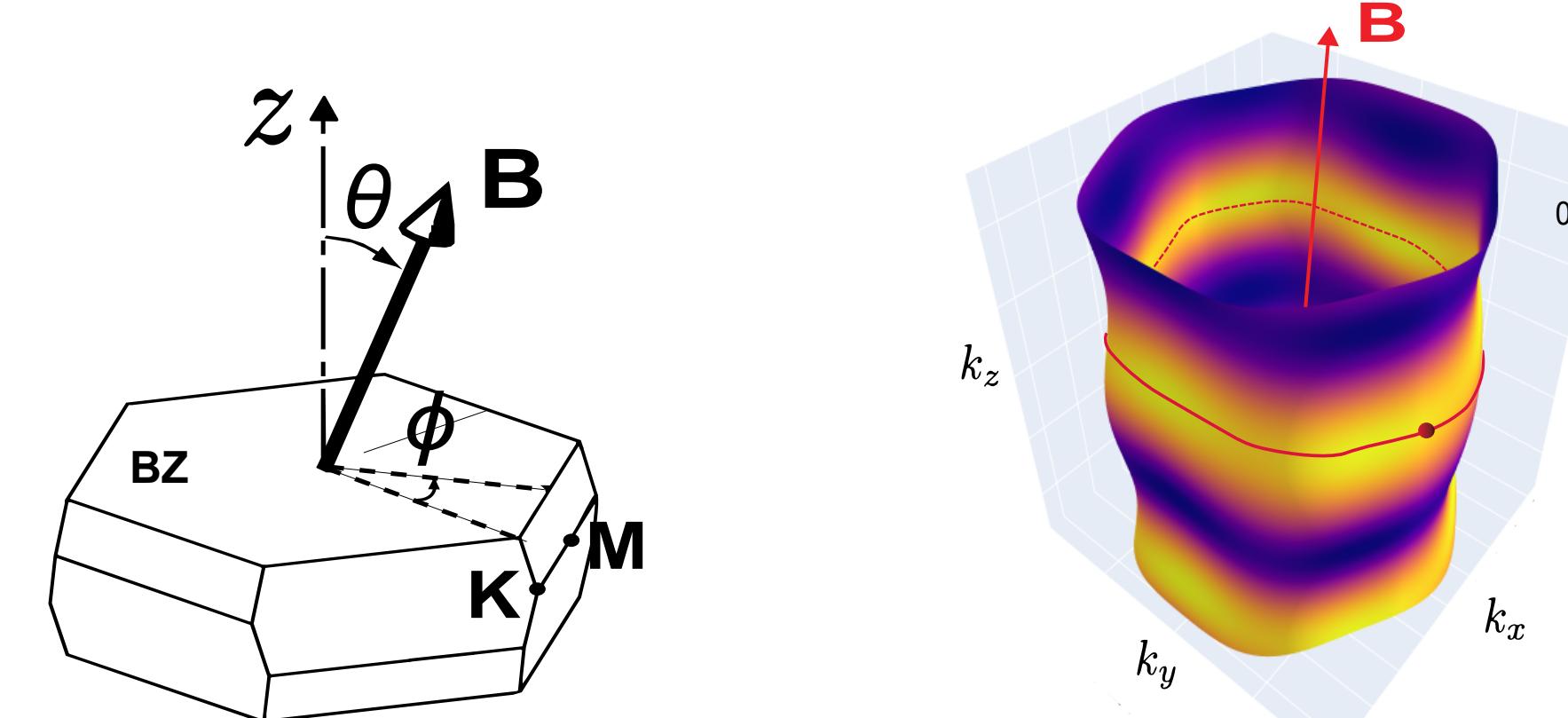
Under strong magnetic fields, electrons follow cyclotron orbits along the Fermi surface (FS), whose trajectory is given by the Lorentz force:

$$\hbar \frac{d\vec{k}}{dt} = -e\vec{v} \times \mathbf{B}$$

Electrons scatter after a time τ . If the orbits are closed and completed (i.e. the cyclotron frequency ω_c follows $\omega_c \tau \sim 1$), the velocity in the plane is averaged to zero and the resistivity increases.

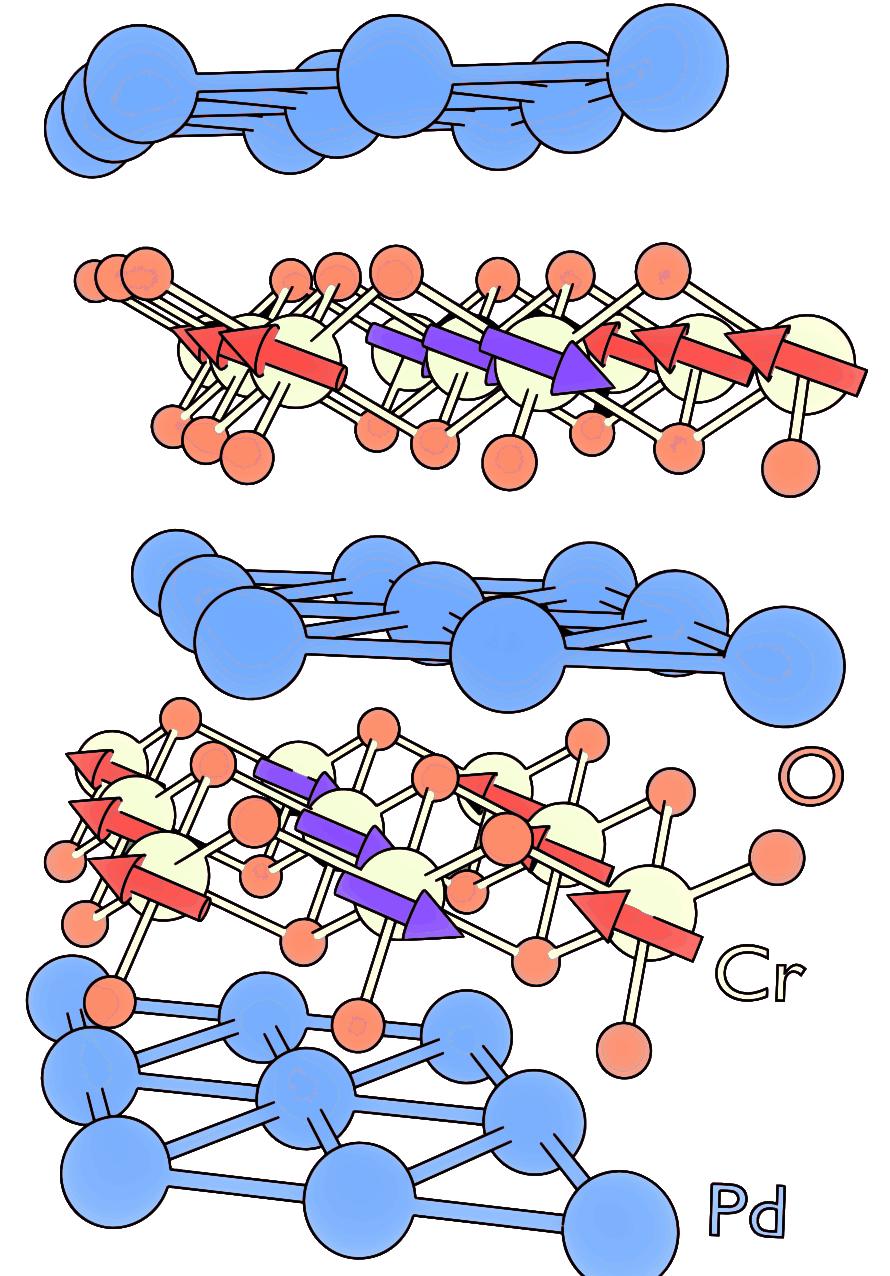
These orbits depend directly on the topology of the FS and the value of the k-dependent scattering time, $\tau_k(T)$, along the orbit trajectory. From the ADMR, the FS and $\tau_k(T)$ are extracted using Boltzmann semiclassical transport theory and Chamber's formula:

$$1/\rho_{zz} = e^2 \int_{FS} \frac{dk^2}{(2\pi)^3} \frac{v_z(\mathbf{k}(t=0))}{\hbar|\vec{v}(\mathbf{k})|} \int_0^\infty v_z(\mathbf{k}(t)) e^{-t/\tau}$$



Discussion^{1,2,3,4,5}

Delafoseites are layered quasi 2D materials made of highly conductive planes, consisted of Palladium atoms here, and separated by insulating oxide planes. In the case of PdCrO₂, these oxide planes are magnetic, and show frustration until the antiferromagnetic (AFM) phase is achieved at 37.5K. Due to its frustration, AFM fluctuations survive way above the transition temperature, in the same region where the resistivity becomes linear. Differently, PdCoO₂ does not have magnetic oxide layers nor T-linear resistivity, although both materials are completely isostructural with the same Fermi surfaces. This suggest that the AFM fluctuations are responsible for the stark difference between these materials.



Results

At 15K, our data show the most striking difference. In PdCoO₂, there is no AFM phase. Its Fermi surface remains unchanged, and we observe regular and fast oscillations all the way up to 100K. For PdCrO₂, in the AFM phase, ADMR reveals a rich display of smaller oscillations, following the folding of the Brillouin Zone caused by the new periodicity imposed by the AFM order. This is the reason why we observe such contrast in our data at 15K, despite both materials behaving like good metals.

Above the Neel Temperature at 37.5K, both materials have the same Fermi surface. However, the oscillations in the ADMR of PdCrO₂ are completely damped by the sudden rise in the scattering rate that seem to occur right outside of the AFM phase.

Despite the prominent features being smoothed out, we are still left with some important similarities in the ϕ angle, this is particularly visible when one compares PdCoO₂ at T = 80K and PdCrO₂ at T = 45 K. Indeed, once can see that the ϕ dependence is the same at $\theta = 90^\circ$, with a dip for $\phi = 30^\circ$, and a maximum for $\phi = 0^\circ$.

State of the project

The data were taken in April 2024, now we need to model the ADMR using Boltzmann transport in order to extract the scattering time from the data. To achieve this goal, we will use the electronic bands measured by ARPES and modeled by DFT + DMFT. This project will require additional development compared to the cuprate strange metal study⁵ as PdCrO₂ has an hexagonal lattice, and calculations take much more time because of the long cyclotron orbits in these clean metals.

