Evidence of hot and cold spots on the Fermi surface of LiFeAs

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Angle-resolved photoemission spectroscopy (ARPES) is used to study the energy and momentum dependence of the inelastic scattering rates and the mass renormalization of charge carriers in LiFeAs at several high symmetry points in the Brillouin zone. A strong and linear-in-energy scattering rate is observed for sections of the Fermi surface having predominantly Fe 3d_{xy/yz} orbital character on the inner hole and on electron pockets. We assign them to hot spots with marginal Fermi liquid character inducing high antiferromagnetic and pairing susceptibilities. The outer hole pocket, with Fe 3d_{xy} orbital character, has a reduced but still linear in energy scattering rate. Finally, we assign sections on the middle hole pockets with Fe 3d_{x^2-y^2} orbital character and on the electron pockets with Fe 3d_{xy} orbital character to cold spots because there we observe a quadratic-in-energy scattering rate with Fermi-liquid behavior. These cold spots prevail the transport properties. Our results indicate a strong momentum dependence of the scattering rates. We also have indications that the scattering rates in correlated systems are fundamentally different from those in non-correlated materials because in the former the Pauli principle is not operative. We compare our results for the scattering rates with combined density functional plus dynamical mean-field theory calculations. The work provides a generic microscopic understanding of macroscopic properties of multiorbital unconventional superconductors.

Introduction. Since the discovery of iron-based superconductors (FeSCs) [1] there is an ongoing debate about whether their electronic structure is more itinerant or localized [2]. Transport properties and optical spectroscopy indicate predominantly a Fermi liquid behavior [3–5]. On the other hand, high-Tc s± superconductivity and antiferromagnetism are believed to occur due to strong correlation enhanced scattering of the charge carriers between hole and electron pockets [6]. In these multi-orbital systems, it is likely that the different properties are related to the intrinsic multi-orbital nature of electron and hole pockets. This is supported by combined density functional plus dynamical mean field theory (DFT+DMFT) calculations, which pointed out that the strength of the correlation effects strongly depends on the orbital character of the bands due to their different respective filling [7–13] and that for half-filled orbitals, correlation effects are not only determined by the onsite Coulomb interaction but also by Hund’s exchange interaction.

The strength of correlation effects, however, may be determined not only by the orbital character of the bands but also by the nesting conditions and, thus, by the momentum [14, 15]. In order to obtain a microscopic understanding of these effects, momentum dependent information on the character of the states near the Fermi level (E_F) is necessary. Angle-resolved photoemission spectroscopy (ARPES) is a suitable method to obtain this momentum dependent information because it provides the energy (E) and momentum (k) dependent scattering rates Γ or lifetimes τ = ℏ/Γ of the charge carriers [16] which are related to the imaginary part of the self-energy Σ by Γ = −2ZΣ, where Z = m*/m = 1−2ZΣ is the quasiparticle residue and m*/m is the mass renormalization [17]. The latter is derived from a comparison of the ARPES data with DFT calculations. Here, we use ARPES to study the scattering rate of superconducting LiFeAs [18] in its normal state. This tetragonal compound without dopant atoms to induce disorder, is particularly suited for ARPES studies [19–21].

There are numerous ARPES studies on LiFeAs [22–29]. In the investigations of the scattering rates, one of the main results was that Γ depends on the orbital character rather than on the position on the Fermi surface. This result was possibly biased by DFT+DMFT calculations on FeSCs [30, 31] which are based on a local, not momentum dependent approximation for the correlation effects. The present high resolution ARPES data together with a new evaluation method comes to a different conclusion: the inelastic scattering rates depend predominantly on the momentum and only indirectly on the orbital character. Our study yields information on the location of hot (large Γ) and cold (small Γ) spots within the Brillouin zone (BZ). This will improve our microscopic understanding of the magnetic and superconducting susceptibilities (determined by the hot spots) and normal state transport properties (determined by the cold spots).

Experimental. LiFeAs (T_c = 17 K) single crystals were grown using the self-flux technique [32]. ARPES measurements were conducted at the I^2 and I^4-ARPES end stations attached to the beamline UE112 PGM at
FIG. 1. (a) Schematic Fermi surface of LiFeAs in the $k_z = 0$ plane. Sections with different orbital character are marked by different colors [14, 15]. (b) - (f) Energy momentum distribution maps (EMDM) measured at various points indicated in (a). Red lines: dispersions derived from fits of ARPES data. Dashed white lines: dispersions from DFT calculations. Solid white lines: dispersions from DFT+DMFT calculations. (b) Data from the inner hole pocket with $d_{xz}$ orbital character, measured near $\Gamma$ [point (1)] along cut I with $s$-polarized photons (energy $h\nu = 82$ eV). (c) Zoom into the top of the inner hole pocket. (d) Similar data as in (b) but measured with $p$-polarized light (energy $h\nu = 49$ eV). The outer [$d_{xy}$ orbital character, point (3)] and the middle [$d_{xz}$ orbital character, point (2)] hole pockets are visible. (e) EMDM measured along cut I near $M_y$ with $s$-polarized photons ($h\nu = 123$ eV) showing the outer electron pocket [$d_{xy}$ orbital character, point (4)]. (f) EMDM measured with $s$-polarized photons ($h\nu = 84$ eV) along cut II showing the electron pocket [$d_{yz}$ orbital character, point (5)] near the $M_x$ point.

BESSY, equipped with Scienta R8000 and Scienta R4000 energy analyzers, respectively. All data presented in this contribution were taken in the normal state at temperatures between 20 and 35 K. The achieved energy and angle resolutions were between 4 and 15 meV and $0.2^\circ$, respectively. Polarized photons with energies $h\nu = 20 - 130$ eV were employed to reach different $k_z$ values in the BZ and spectral weight with a specific orbital character [33, 34]. An inner potential of 12 eV was used to calculate the $k_z$ values from the photon energy [35].

Data evaluation and electronic structure calculations. Usually, in ARPES the scattering rates are derived from the width of the spectral weight at constant energy [16, 36]. The lifetime broadening in energy space is obtained by multiplying the momentum width by the velocity. This works well for a linear dispersion because in this case the velocity $v$ is constant in energy and therefore the contribution from the elastic scattering is constant. It is also possible to evaluate the inelastic lifetime broadening from a parabolic dispersion but then one has to take into account the energy dependence of the velocity. At the top and the bottom the velocity is zero and therefore this method does not work at these energies. In the present work we use a multivariate fit of the measured data which is superior to the methods described above. The finite energy and momentum resolution was taken into account by convolutions with Gaussian functions. To obtain the inelastic scattering rates due to electron-electron interaction we subtracted the energy dependent elastic scattering rates $\Gamma_b(E)$. The later is calculated from the relation $\Gamma_b(E) = v(E)w_0$. The velocity $v(E)$ is taken from the ARPES dispersion. The momentum width $w_0$ at $E_F$, corresponding to the inverse mean free path, can be derived using $\Gamma_i(0) = \Gamma_e(0) + v(0)w_0$. This follows from the fact that the inelastic scattering rate $\Gamma_i(0)$ is zero at $E_F$ [37].

We performed density functional band structure calculations within the local density approximation including spin orbit coupling, using experimental structural parameters [18] and the full-potential local-orbital code FPLO [38] (version fplo18.0.0-52) with the Perdew-Wang exchange correlation potential [39]. Similar to earlier DFT+DMFT studies [40, 41], the local self-energies due to the correlated Fe 3$d$ problem, intrinsic to Fe-based superconductors are obtained with the multi-orbital iterated perturbation theory as impurity solver [42], where $U = 2.5$ eV and $J_H = 0.7$ eV are used.

From a parabolic fit to the ARPES data and to the
DFT results close to $E_F$ we derive the renormalized mass $m^*$ and the bare particle mass $m_b$, respectively. The ratio $m^*/m_b$ yields the mass renormalizations.

Results. In Fig. 1(a) we present a schematic Fermi surface of typical ferropnictides in a selected region in reciprocal space in the $k_z = 0$ plane. In LiFeAs for $k_z=0$, no inner hole pocket is visible in the Fermi surface because it is about 12 meV below $E_F$. Using thick black solid lines we mark two cuts (I and II) along which we have performed ARPES measurements. In Fig. 1(b)-(f) we show energy-momentum distribution maps of hole and electron pockets, recorded along cut I and cut II using different photon polarizations to select bands with different orbital character [33]. To demonstrate the existence of spectral weight with yz orbital character at $E_F$ due to a correlation induced broadening of the band, we show a zoom in of Fig. 1(b) in Fig. 1(c). In Fig. 1(b)-(f) we have added the dispersions calculated by DFT and DFT+DMFT. Using other photon energies, we have collected analogous data of the spectral weight in planes corresponding to $k_z = \pi/c$.

In Fig. 2 we compare $\Gamma_i(E)$ from ARPES with DFT+DMFT results. As shown previously for the inner and outer hole pocket in other ferropnictides [43], for all points the theoretical values are considerably smaller than the experimental data. In the analyzed energy regions, the data for points (1), (3), and (5) can be well fitted by a linear relationship $\Gamma = \beta E$. At points (2) and (4) $\Gamma_i$ can be fitted by a quadratic relationship $\Gamma = \gamma E^2$. We have not found a clear indication of significant electron-phonon coupling which would result in a step in $\Gamma_i(E)$ and a kink in the dispersion near the Debye energy of $\approx 0.03$ eV [44]. In the case when a band does not cross $E_F$, e.g. the top of the inner hole pocket is $\approx 0.012$ eV below $E_F$, the data are limited at low energies. At high energies the data are limited by a finite band width, overlapping bands, or in the case when the spectral weight can no longer be distinguished from the background.

The parameters describing the energy dependence of the inelastic scattering rates ( $\beta$ and $\gamma$) are collected in Table I for data corresponding to $k_z = 0$ and $k_z = \pi/c$. In addition we present values of $\Gamma_0$ which is used to subtract the contributions from $\Gamma_e$ (see above and Supplement [45]). The error bars are estimated from the analysis of data taken at different photon energies and different Brillouin zones.

Moreover we present in Table I the derived mass renormalizations near $E_F$. These mass renormalizations slightly decreases with increasing binding energy (not shown). Within error bars there is no $k_z$ dependence of all values presented in Table I.

Discussion. Comparing the experimental, the DFT, and the DFT+DMFT dispersions (see Fig. 1), in all cases the mass renormalization near $E_F$ is well described by DFT+DMFT calculations. Also no shift between the ARPES data and the DFT+DMFT results is observed at points (3), (4), and (5). However, near $k = 0$ and $k_F$, shifts of about 0.07 eV to higher energies are observed at points (1) and (2) between the DFT dispersion and the ARPES dispersion. This shift leads to a shrinking or disappearance of the middle and the inner hole pockets, respectively. This shift is not reduced near the calculated $k_F$ points by DFT+DMFT calculations (see also Ref. [31, 46]).

Regions with a linear increase of the scattering rates as a function of energy have been detected in other FeSCs and related compounds and were discussed in previous publications [43, 47–49] in terms of momentum and not orbital dependent strong correlation effects and the proximity to the Planckian limit [50].

Interestingly, the scattering rate at point (1) extrapolates to zero and not to the top of the band at $E_i \approx 0.012$ eV. The latter is expected for a normal Fermi liquid behavior because interband transitions between the in-
TABLE I. ARPES data of LiFeAs derived at various high-symmetry points (HSP) [Fig. 1 (a)] for $k_z = 0$ and $k_z = \pi/c$ having predominantly an orbital character OC. $m^*/m_b$ is the mass renormalization. $w_0$ is the momentum width near $E_F$ caused by elastic scattering. $\beta$ gives the slope in regions of a linear energy dependence of the scattering rate for points (1), (3), and (5). The parameter $\gamma$ is related to the quadratic increase of the scattering rates at points (2) and (4). n.a. means not applicable.

| HSP | OC  | $m^*/m_b$ | $w_0 (\text{Å}^{-1})$ | $\beta$ | $\gamma$ (eV)$^{-1}$ | $m^*/m_b$ | $w_0 (\text{Å}^{-1})$ | $\beta$ | $\gamma$ (eV)$^{-1}$ |
|-----|-----|-----------|------------------------|---------|----------------------|-----------|------------------------|---------|----------------------|
|     |     |           |                        |         |                      |           |                        |         |                      |
| (1) | yz  | 1.6±0.4   | 0.00±0.01              | 1.3±0.1 | n.a.                 | n.a.      | n.a.                   | n.a.    | n.a.                 |
| (2) | $xz$| 1.3±0.5   | 0.03±0.1               | n.a.    | 5±4                  | 2±0.2     | 0.03±0.1              | n.a.    | 18±4                 |
| (3) | $xy$| 3.9±0.1   | 0.03±0.01              | 0.3±0.1 | n.a.                 | 3.6±0.1   | 0.05±0.03             | 0.7±0.2 | n.a.                 |
| (4) | $xy$| 4.8±0.2   | 0.05±0.01              | n.a.    | 32±5                 | 3±1       | 0.01±0.02             | n.a.    | 25±5                 |
| (5) | $yz$| 2.3±0.1   | 0.05±0.01              | 0.7±0.1 | n.a.                 | 1.8±0.1   | 0.10±0.02             | 0.6±0.2 | n.a.                 |


errer hole pocket and the inner electron pocket are not allowed for energies less than $E_f$ because of the Pauli principle. This was also discussed for the superconducting case where the scattering rate should go to zero at three times the superconducting gap energy $\Delta$ [51]. However, in highly correlated systems in which the Fermi edge in momentum space is broadened, the Pauli principle is no more operative [52] and therefore the scattering rate should extrapolate to zero at a finite lifetime broadening at $E_f$. The experimental observation that $\Gamma_i(E)$ extrapolates to zero and not to $E_f$ is an important result indicating that interband transitions and their related properties such as magnetic or pair susceptibilities are fundamentally different between correlated and uncorrelated systems. In this context, we mention recent ARPES data on Ni in which also an extrapolation of the linear-in-energy scattering rate to zero was observed for the gapped majority Ni 3$d$ band [53]. A detailed discussion of the interband transition is presented in the Supplement [54].

Different from our previous studies on BaFe$_2$(As$_{1-x}$P$_x$)$_2$ and EuFe$_2$(As$_{1-x}$P$_x$)$_2$ [47] in which all energy dependencies of the inelastic scattering rates were assumed to be linear, we observe in the present investigation for the middle hole pocket and for $d_{xy}$ sections on the electron pockets [point (4)] a Fermi liquid behavior, i.e., a quadratic increase as a function of energy, in agreement with DFT+DMFT: $\Gamma_i = \gamma E^2$ (Fig. 2). This indicates coherent electronic states at this point at low energies. The prefactor $\gamma \approx 30$ eV$^{-1}$ of this energy dependence at point (4) is very large which leads to a crossover to incoherent states at rather low energies of $\approx 0.03$ eV corresponding to room temperature. We contrast the large prefactor $\gamma \approx 30$ eV$^{-1}$ detected at this point with a much smaller prefactor $\gamma \approx 0.28$ eV$^{-1}$ derived for a weakly correlated electronic structure of a Mo surface [36]. Regarding the steep energy dependence, an orbital selective crossover has been detected as a function of temperature in ARPES measurements of FeSCs [26, 55, 56].

Naively one would expect that because of the connection of $\Re \Sigma$ with $3 \Sigma$ by the Kramers-Kronig relation, the mass renormalization $m^*/m_b$ would scale with the strength of the scattering rates. Looking at Table I to the data at point (1) and (3) the ratio between $m^*/m_b$ and $\beta$ is about 0.4 and 3, respectively. Regarding the relationship between $\Gamma_i, Z, m^*/m_b,$ and $3 \Sigma$ presented in the Introduction, a small scattering rate together with a small $Z$ (large $m^*/m_b$) yields a large $3 \Sigma$ and thus via the Kramers-Kronig relation a large mass renormalization. This shows that also the data for $\Gamma_i$ and $m^*/m_b$ at points (1) and (3) may be compatible with the Kramers-Kronig relation.

We point out that the location of the hot spots coincides with regions where the highest superconducting gaps were detected [24, 57]. In particular we mention that the inner $yz$ hole is still important for superconductivity because due to correlation induced broadening of the bands there is still spectral weight at $E_F$ [see Fig. 1(c)]. The reason for this is that the difference between $E_F$ and the maximum of the band ($E_i \approx 0.012$ eV) is smaller than the coupling energies of spin fluctuation (of the order of 0.01 to 0.1 eV [2]) and should therefore, in an Eliashberg model, contribute to the superconducting transition temperature [58]. The present discussion is also important for many other iron-based superconductors, e.g. the ferrochalcogenides, where the top of the hole pockets are very close to $E_F$.

The observation of Fermi liquid behavior on hole and electron pockets is in line with transport data [59] which derived a Fermi liquid behavior both in hole and electron pockets. Quantum oscillation experiments [60, 61] came to the conclusion that the scattering rates for electrons are smaller than those of holes in agreement with the present result. Their derived mass enhancements are comparable to the present results. Regarding the quadratic increase of $\Gamma_i$ at points (2) and (4) we mention that our data are also consistent with optical spectroscopy data [4, 5] because the optical conductivity in a multi-orbital system is dominated by cold spots.

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Data evaluation. ARPES measures the energy ($E$) and momentum ($k$) dependent spectral function $A(E,k)$ multiplied by a transition matrix element and the Fermi function and convoluted with the energy and momentum resolution [1]. The spectral function is given by

$$A(E,k) = \frac{1}{\pi} \frac{\Gamma(E,k)}{[E - \epsilon_k^*]^2 + \left[\frac{\Gamma(E,k)}{2}\right]^2},$$

where $\Gamma$ is the lifetime broadening of the photo hole in the valence band and $\epsilon_k^*$ is the renormalized particle energy. $\epsilon_k = E_k - \Re \Sigma(E,k)$ and $\Gamma(E,k) = -2Z(E,k)\Im \Sigma(E,k)$. Here $E_k$ is the bare particle energy, $\Sigma$ is the is complex self-energy and $Z(E,k)$ is the renormalization function. Strictly speaking the formula for the spectral function is only valid near the Fermi level and for a small self-energy independent of momentum [2]. In this case the spectral function at constant momentum has a maximum at $\epsilon_k^*$ and a full width at half maximum of $\Gamma$. Very often the description of the spectral function is extended to higher energies [3, 4].

Normally the analysis of the lifetime broadening is performed by taking slides through the measured intensity either at constant momentum or constant energy. The former method has the disadvantage that it is influenced by the Fermi function and an energy dependent background. Thus most of the studies use the latter method [1]. In this case the momentum distribution curves are fitted with Lorentzians yielding the momentum width. The energy width is then calculated by multiplying this momentum width with the velocity. However also this method has drawbacks. In regions close to the top or the bottom of pockets the velocities are small and the momentum width is large. In the present ARPES study of LiFeAs this occurs at the top of the inner and the middle of the hole pockets and near the bottom of the inner electron pocket. In those regions the finite energy and momentum resolution is of importance.

Therefore we have analyzed our spectra by a multivariate fit of the spectra measured in the two-dimensional $E - k$ space. We multiply the spectral function with the Fermi function and convolute it with the energy and momentum resolution. Waterfall plots of the energy and momentum dependent ARPES data together with a fit are presented in Figs. 1-5. The assignment of the data corresponds to Fig. 1(a) of the main text. The following parameters were derived: the energy dependent lifetime broadening $\Gamma(E)$ for all measured energies, a constant slightly asymmetric amplitude, values determining the dispersion, and values determining the slightly energy and momentum dependent background. In nearly all cases the fits are rather good. For the inner hole pocket (Fig. 5) the fit is less perfect probably due to small contributions to the spectral weight from the outer hole pocket.

FIG. 1. Waterfall plot of LiFeAs ARPES data (black dots) on the inner hole pocket (point (1)) together with a fit (green solid lines). The energy of the spectra range from 0.15 eV (lowest spectrum) to 0.02 eV (uppermost spectrum). The energy difference between the spectra is 0.006 eV.
FIG. 2. (Color online) Waterfall plot of LiFeAs ARPES data (black dots) on the middle hole pocket [point (2)] together with a fit (green lines). The energy of the spectra range from 0.0324 eV (lowest spectrum) to 0.0012 eV (uppermost spectrum). The energy difference between the spectra is 0.0024 eV. Contributions from the middle hole pocket are suppressed by a mask.

FIG. 3. Waterfall plot of LiFeAs ARPES data (black dots) on the outer hole pocket [point (3)] together with a fit (green solid lines). The energy of the spectra range from 0.076 eV (lowest spectrum) to -0.01 eV (uppermost spectrum). The energy difference between the spectra is 0.006 eV. Contributions from the inner and the middle hole pocket are suppressed by a mask.

FIG. 4. Waterfall plot of LiFeAs ARPES data (black dots) on the outer electron pocket [point (4)] together with a fit (green solid lines). The energy of the spectra range from 0.0465 eV (lowest spectrum) to 0.0045 eV (uppermost spectrum). The energy difference between the spectra is 0.003 eV.

FIG. 5. Waterfall plot of LiFeAs ARPES data (black dots) on the inner electron pocket [point (5)] together with a fit (green solid lines). The energy of the spectra range from 0.0285 eV (lowest spectrum) to 0.0075 eV (uppermost spectrum). The energy difference between the spectra is 0.003 eV.

In this way we obtain the energy dependent total scat-
Scattering rates of holes in LiFeAs at five different points in the Brillouin zone. Open circles: total scattering rates $\Gamma_t(E)$; closed circles: inelastic scattering rates $\Gamma_i(E)$. For point (1) we only show $\Gamma_i(E)$ because the corrections due to elastic scattering are small.

In highly correlated systems the latter is predominantly due to electron-electron interaction. To derive $\Gamma_i(E)$ one has to subtract the elastic from the total scattering rates. $\Gamma_e(E)$ is usually assumed to be constant [4]. However, this holds only for a linear dispersion when the velocity $v(E)$ is constant because $\Gamma_e(E) = v(E)w_0$, where $w_0$ is the momentum width at the Fermi level related to the constant inverse mean free path between scattering sites inducing elastic scattering. To obtain the inelastic lifetime broadening for a parabolic dispersion, one has to subtract the energy dependent $\Gamma_e(E)$ from $\Gamma_t(E)$. In this context we mention that an energy dependent lifetime broadening on the basis of a constant momentum width has been discussed for Cu surface states [5, 6]. $w_0$ can be calculated from the data near $E_F$ because there $\Gamma_i(0)$ is zero and thus $\Gamma_e(0) = \Gamma_t(0) = v(0)w_0$; $v(E)$ is taken from the measured dispersion. This method cannot be used for those pockets which do not cross the Fermi level, i.e., the inner and the middle hole pocket. In this case we have used values from the $k_z = \pi$ plane where the middle hole pocket crosses the Fermi level. The $w_0$ values differ between different points. A theoretical explanation for this was presented recently from calculations of the elastic scattering rates at different sites of the Brillouin zone [7].

In Fig. 6 we present the total scattering rates $\Gamma_t(E)$ together with $\Gamma_i(E)$. This figure clearly demonstrates that corrections of an energy dependent scattering rate is rather important for the strongly non-linear dispersions in LiFeAs.

Differences of the scattering rates between a weakly correlated and a strongly correlated system. In this section we describe Augerlike interband transitions between

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**FIG. 6.** Scattering rates of holes in LiFeAs at five different points in the Brillouin zone [see Fig. 1(a) of the main text]. Open circles: total scattering rates $\Gamma_t(E)$; closed circles: inelastic scattering rates $\Gamma_i(E)$. For point (1) we only show $\Gamma_i(E)$ because the corrections due to elastic scattering are small.

**FIG. 7.** (Color online) Relaxation process of a photo-hole in a hole pocket due to interband transitions between the hole pocket and an electron pocket. Black empty circle: initial photo hole. Open red circles: relaxed hole in the hole pocket and hole in the electron pocket. Filled circle: excited electron in the electron pocket. The black and the red symbols correspond to the initial and the final final state, respectively. (a) Transitions between an ungaped hole pocket and an electron pocket. (b) and (c) Analogous to (a) but for a gaped hole-pocket. (d) Analogous to (b) but for a highly correlated system.
a hole pocket and an electron pocket which are related to the inelastic electron-electron scattering rate in hole pockets of LiFeAs. These transitions may also mediate antiferromagnetism and superconductivity in ferropnictides [8]. These transitions are illustrated in Fig. 7. In Fig 7(a) we depict interband transitions in a weakly correlated system which lead to a relaxation of a hole, produced in the photoemission process, to lower energies. This leads in essence to a mass enhancement. The photo-hole is filled by an interband transition from the electron pocket. The energy is transferred to an interband transition from a state of the hole pocket at lower energies to unoccupied states of the electron pocket. Transitions into occupied electron pocket states are forbidden due to the Pauli principle. If the hole band is below $E_F$ [see Fig. 7(b) and (c)] transitions from the hole band to the electron band are only possible when the energy of the interband transition is larger than the energy of the top of the hole pocket $E_t$ [see Fig. 7(c)]. Thus at the top of the hole band the scattering rate should go to zero because the phase space for the transition disappears.

However, the situation is completely different for a strongly correlated system. There the Fermi edge in momentum space is broadened leading to unoccupied states below the Fermi momentum. Therefore interband transitions into states from the electron pocket below the Fermi level are allowed. The reason for this is that the Pauli principle in this case is no more operative. This leads to a finite phase space for interband transitions even at the top of the hole pocket and therefore to a finite scattering rate. This is illustrated in Fig. 7(d). Thus there is a fundamental difference of the scattering rates between weakly correlated and strongly correlated systems. A similar argumentation was used to explain the enhanced scattering rates at low energies in highly correlated systems leading to the appearance of marginal Fermi liquids [9].

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