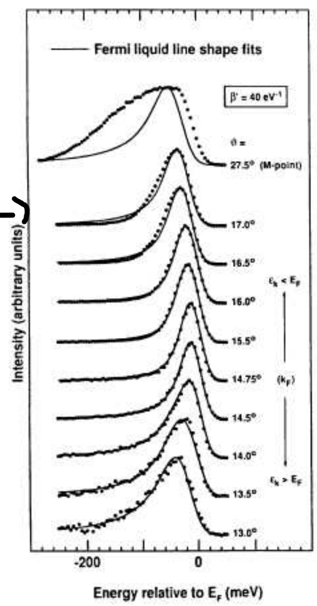

Figure 28-1 ARPES spectrum of $1-T-TiTe_2$, after R. Claessen, R.O. Anderson, J.W. Allen, C.G. Olson, C. Janowitz, W.P. Ellis, S. Harm, M. Kalning, R. Manzke, and M. Skibowski, Phys. Rev. Lett **69**, 808 (1992).

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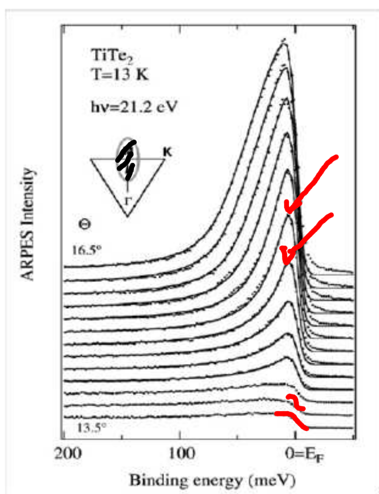
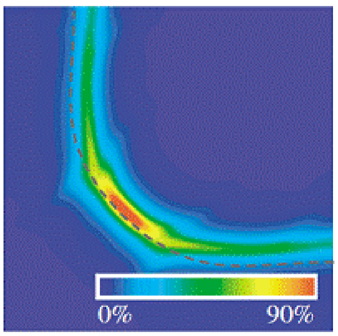


Figure 28-2 Figure 1 from Ref.[19] for the ARPES spectrum of $1T$-TiTe$_2$ measured near the Fermi surface crossing along the high-symmetry ΓM direction ($\theta = 0$ is normal emission). The lines are results of Fermi liquid fits and the inset shows a portion of the Brillouin zone with the relevant ellipsoidal electron pocket.

$$\Gamma = -Z_k \, \mathrm{Im}\, \Sigma^R$$
$$= Z_k (\gamma) \omega^2 = \gamma' \omega^2$$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28. Signification physique du poids spectral: Q.P., m^*, Z_k, n_k

→ 1. $A(k,\omega)$ sans interaction

→ 2. Repr. de Lehmann

→ 3. Interprétation probabiliste

→ 4. Analogue du théorème de F.-D.

5. Expériences ARPES

→ 6. Quasiparticules

7. Liquides de Fermi

8. n_k système en interaction

29. Résultats formels

1. Comportement $\omega \to \infty$

2. Causalité

28.1 A sans interaction

$$A(k,\omega) = i\left(G^R(k,\omega) - G^A(k,\omega)\right) \qquad \boxed{G(k,z) = \int \frac{d\omega'}{2\pi} \frac{A(k,\omega')}{z-\omega'}}$$

$$G^R(k,\omega) = \frac{1}{\omega + i\eta - \xi_k} \qquad G^R \quad z = \omega + i\eta$$

$$G^A \quad z = \omega - i\eta$$

$$A(k,\omega) = 2\pi\,\delta(\omega - \xi_k) \qquad \xi_k = \epsilon_k - \mu$$

28.2 Repr. de Lehmann

$$A(r,r',\omega) = \int dt\, e^{i\omega t} \left\langle \left\{ \psi(r,t), \psi^\dagger(r') \right\} \right\rangle$$

$$\rho = \frac{e^{-\beta K}}{Z}$$

$$\Omega = -T \ln Z$$

$$Z = e^{-\beta\Omega}$$

$$= e^{\beta\Omega} \int dt\, e^{i\omega t} \sum_{mn} \Big[e^{-\beta K_n} \langle n | \overbrace{e^{iKt}}^{K_n} \psi_s(r) \overbrace{e^{-iKt}}^{K_m} | m \rangle \langle m | \psi_s^\dagger(r') | n \rangle$$

$$+ e^{-\beta K_n} \langle n | \psi_s^\dagger(r') | m \rangle \langle m | e^{iKt} \psi_s(r) e^{-iKt} | n \rangle \Big]$$

$$= e^{\beta\Omega} \sum_{m,n} \Big\{ e^{-\beta K_n} \langle n | \psi_s(r) | m \rangle \langle m | \psi_s^\dagger(r') | n \rangle 2\pi\, \delta(\omega + K_n - K_m)$$

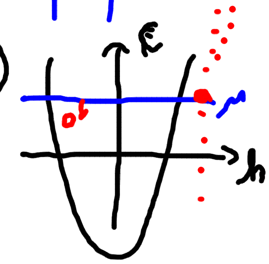
$$+ e^{-\beta K_n} \langle n | \psi_s^\dagger(r') | m \rangle \langle m | \psi_s(r) | n \rangle 2\pi\, \delta(\omega + K_m - K_n) \Big]$$

$T=0$

$$\text{BIS:}\quad \omega + (E_0 - N_0\mu) - (E_m - (N_0+1)\mu)$$

$$= \omega + \mu + E_0 - E_m$$

$$\text{ARPES} = \omega + \mu + E_m - E_0 \qquad E_m - E_0 \approx \mu$$



28.3 Interprétation probabiliste

$$A(k,\omega) = e^{\beta\Omega} \sum_{m,n} \Big(e^{-\beta K_n} \langle n|c_k|m\rangle \langle m|c_k^{+}|n\rangle 2\pi\, \delta(\omega + K_n - K_m)$$

$$+ e^{-\beta K_n} \langle n|c_k^{+}|m\rangle \underline{\langle m|c_k|n\rangle} 2\pi\, \delta(\omega + K_m - K_n) \Big)$$

$$= e^{\beta\Omega} \sum_{m,n} \left(e^{-\beta K_n} + e^{-\beta K_m} \right) \left|\langle n|c_k|m\rangle\right|^2 2\pi\, \delta(\omega + K_n - K_m)$$

k fixe

$$A(k,t=0) = \int \frac{d\omega}{2\pi} A(k,\omega) = \langle \{ c_k, c_k^{+} \} \rangle = 1$$

$e^{i\omega 0}$

23.4 Analogue du théorème F.-D.

$$\frac{d^2\sigma}{d\Omega\, d\omega} \propto \boxed{\int dt\, e^{i\omega t} \langle c_k^\dagger c_k(t) \rangle = \underbrace{f(\omega)} \underbrace{A(k,\omega)}}$$

$$S_{A_iA_j}(\omega) = \int dt\, e^{i\omega t} \langle A_i(t) A_j \rangle = \frac{2}{e^{-\beta\omega}-1} \chi''_{ij}(\omega)$$

$$= \underbrace{\left(1+n_B(\omega)\right)} \underbrace{\int dt\, e^{i\omega t} \langle [A_i(t), A_j(0)] \rangle}$$

Preuve: $\int dt\, e^{i\omega t} \langle \{ c_k(t), c_k^\dagger \} \rangle$

$$\boxed{\int dt\, e^{i\omega t} \left[\langle c_k(t)\, c_k^\dagger \rangle + \langle c_k^\dagger\, c_k(t) \rangle \right]}$$

$$\langle c_k(t) c_k^\dagger \rangle = \frac{1}{Z} \mathrm{Tr}\left[e^{-\beta K} c_k(t)\, c_k^\dagger \right]$$

$$= \frac{1}{Z} \mathrm{Tr}\left[e^{\beta K} e^{-\beta K} c_k^\dagger\, e^{-\beta K} c_k(t) \right]$$

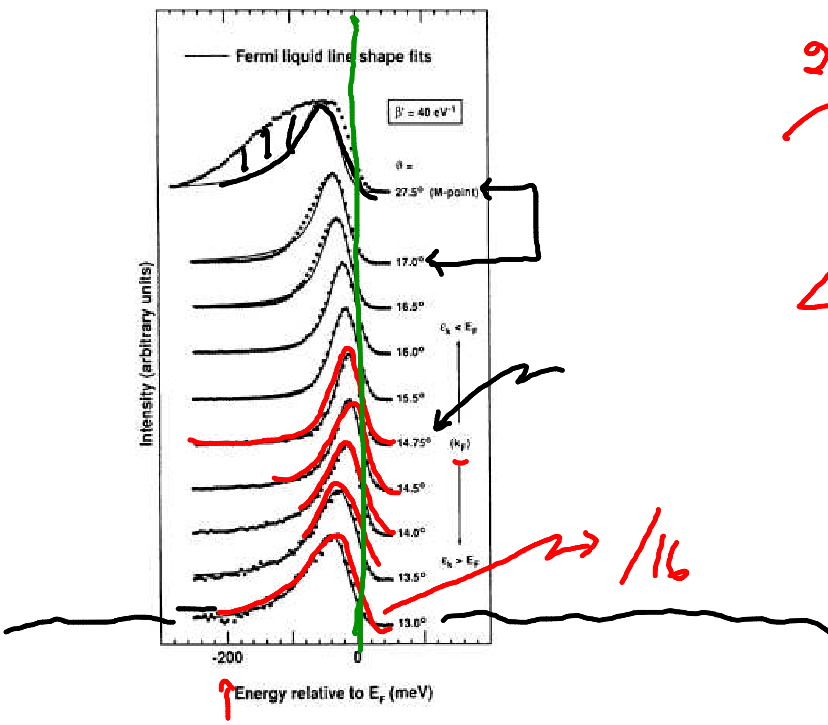
$e^{iH(t+i\beta)}$ $\quad e^{-iH(t+i\beta)}$

$$= \langle c_k^\dagger\, c_k(t+i\beta) \rangle$$

$c_k(t+i\beta)$

$$= \int dt\, e^{i\omega(t+i\beta-i\beta)} \left[\langle c_k^\dagger\, c_k(t+i\beta) \rangle + \langle c_k^\dagger\, c_k(t) \rangle \right]$$

$$A(k,\omega) = \left(e^{\beta\omega} + 1 \right) \int dt\, e^{i\omega t} \langle c_k^\dagger\, c_k(t) \rangle$$



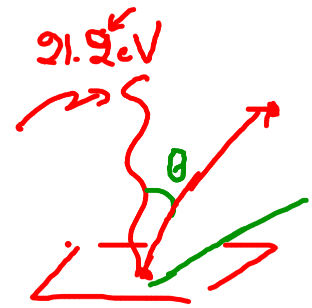


Figure 28-1 ARPES spectrum of $1-T-TiTe_2$, after R. Claessen, R.O. Anderson, J.W. Allen, C.G. Olson, C. Janowitz, W.P. Ellis, S. Harm, M. Kalning, R. Manzke, and M. Skibowski, Phys. Rev. Lett **69**, 808 (1992).

28.6 Quasiparticules

$$G^R(k,\omega) = \frac{1}{\omega - \zeta_k - \Sigma^R(k,\omega)}$$

$$\boxed{\nu_k = \nabla_k \zeta_k}$$

$\omega + i\eta$

$$A(k,\omega) = -2\,\mathrm{Im}\,G^R(k,\omega) = \frac{-2\,\mathrm{Im}\,\Sigma^R(k,\omega)}{\left(\omega - \zeta_k - \mathrm{Re}\,\Sigma^R(k,\omega)\right)^2 + \left(\mathrm{Im}\,\Sigma^R(k,\omega)\right)^2}$$

$\boxed{\omega = E_k - \mu}$ de la Q.P.

satisfait

$$\left(\omega - \zeta_k - \mathrm{Re}\,\Sigma^R(k,\omega)\right) = \underbrace{\left(\quad\right)_{\omega = E_k - \mu}}_{0} + \frac{\partial}{\partial\omega}\left(\omega - \zeta_k - \mathrm{Re}\,\Sigma^R\right)\Big|_{E_k - \mu} (\omega - E_k + \mu)$$

$$= \underbrace{\left[1 - \frac{\partial}{\partial\omega}\mathrm{Re}\,\Sigma^R\Big|_{\omega = E_k - \mu}\right]}_{Z_k^{-1}} (\omega - E_k + \mu)$$

$$A(k,\omega) = 2\pi \, \frac{Z_k}{\pi} \, \frac{-\left(\mathrm{Im}\,\Sigma^R\right) Z_k}{(\omega - E_k + \mu)^2 + \mathrm{Im}\,\Sigma^{R\,2} Z_k^2}$$

$$\boxed{\Gamma(k,\omega) \equiv -Z_k\,\mathrm{Im}\,\Sigma^R(k,\omega)}$$

$$A(k,\omega) = 2\pi\, Z_k \left(\frac{1}{\pi}\, \frac{\Gamma(k,\omega)}{(\omega - E_k + \mu)^2 + \Gamma^2(k,\omega)}\right)$$

cohérente !

$$\int \frac{d\omega}{2\pi} A(k,\omega) = Z_k = \frac{1}{1 - \frac{\partial}{\partial\omega}\mathrm{Re}\,\Sigma^R(k,\omega)}\Bigg|_{\omega = E_k - \mu} < 1$$

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$$\omega_{\text{pôle}} = E_k - \mu$$

$$E_k - \mu - \xi_k - \mathrm{Re}\,\Sigma^R(k, E_k - \mu) = 0$$

$$\nabla_k E_k = v_k^*$$

$$\boxed{v_k^* - v_k - \nabla_k \mathrm{Re}\,\Sigma^R(k, E_k-\mu) - \frac{\partial}{\partial \omega}\mathrm{Re}\,\Sigma^R(k,\omega)\Big|_{\omega = E_k-\mu} v_k^* = 0}$$

Si sphérique.

$$v_k^* - v_k - \frac{\partial}{\partial \xi_k}\mathrm{Re}\,\Sigma^R(\xi_k, E_k-\mu)\, v_k - \frac{\partial}{\partial \omega}\mathrm{Re}\,\Sigma\, v_k^* = 0$$

$$\underset{\frac{1}{m^*}}{v_k^*} = \underset{\frac{1}{m}}{v_k}\, \frac{\left[1 + \frac{\partial}{\partial \xi_k}\mathrm{Re}\,\Sigma^R\right]}{\left[1 - \frac{\partial}{\partial \omega}\mathrm{Re}\,\Sigma^R\right]}\Bigg|_{\omega = E_k - \mu}$$

$$\boxed{m v = \hbar k_F}$$

$$\boxed{m^* v^* = m v}$$

Liquide de Fermi:

Théorème Luttinger: Volume dans zone de Brillouin de la surface de Fermi ne dépend pas des int.

28.7 Liquide de Fermi

À $T=0$ $\quad \underline{\mathrm{Im}\,\Sigma^R(k_F, 0)} = 0$

hypothèse que $\mathrm{Im}\,\Sigma^R$ est analytique en ω

$G^R = G_0^R + G_0^R \Sigma^R G_0^R + \ldots$

$$\mathrm{Im}\,\Sigma^R = \cancel{\alpha\omega} - \gamma\omega^2 + \ldots\ldots$$

$\gamma > 0$

$$\left[\mathrm{Re}\,\Sigma^R(k,\omega) - \underline{\mathrm{Re}\,\Sigma^R(k,\infty)}\right] = \mathcal{P}\int_{-\Omega'}^{\Omega} \frac{d\omega'}{\pi} \frac{-\gamma\omega'^2}{\omega'-\omega}$$

$$= \mathcal{P}\int \frac{d\omega'}{\pi}(-\gamma)\frac{(\omega'^2 - \omega^2 + \omega^2)}{\omega'-\omega} = \mathcal{P}\int \frac{d\omega'}{\pi}(-\gamma)\frac{(\cancel{\omega'-\omega})(\omega'+\omega)}{\cancel{\omega'-\omega}} + \omega^2$$

$$= \boxed{\mathcal{P}\int \frac{d\omega'}{\pi}\omega'(-\gamma)} - \gamma\omega\int_{-\Omega'}^{\Omega} \frac{d\omega'}{\pi} + O(\omega^2)$$

$\Omega + \Omega'$

$\Rightarrow Z_k < 1$