

Cohérence et blocage de Coulomb dans les structures à un électron: un point de vue unifié

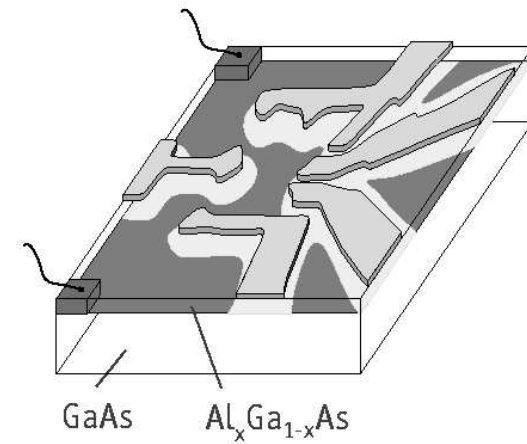
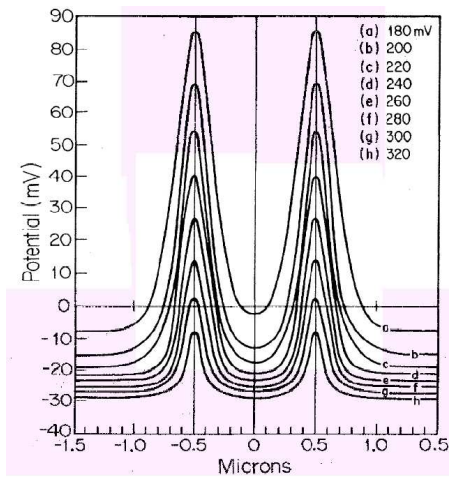
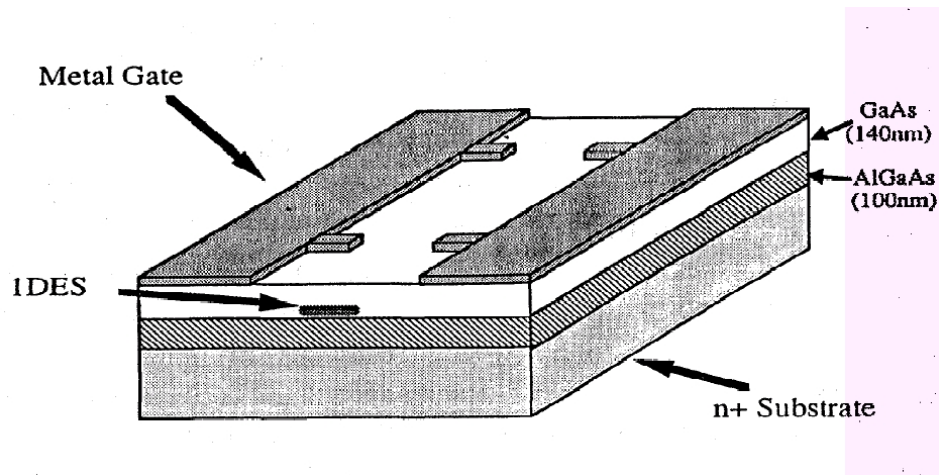
Serge Florens

Laboratoire de Physique Théorique, ENS-Paris

- ⑥ Antoine Georges, *ENS-Paris*
- ⑥ Francisco Guinea, *CSIC-Madrid*
- ⑥ Pablo San Jose, *CSIC-Madrid*

- ⑥ Transistor à un électron:
phénoménologie
- ⑥ Théorie: Coulomb et Kondo (2 en 1)
- ⑥ Régimes intermédiaires de
conduction
- ⑥ Autres applications

Point quantique



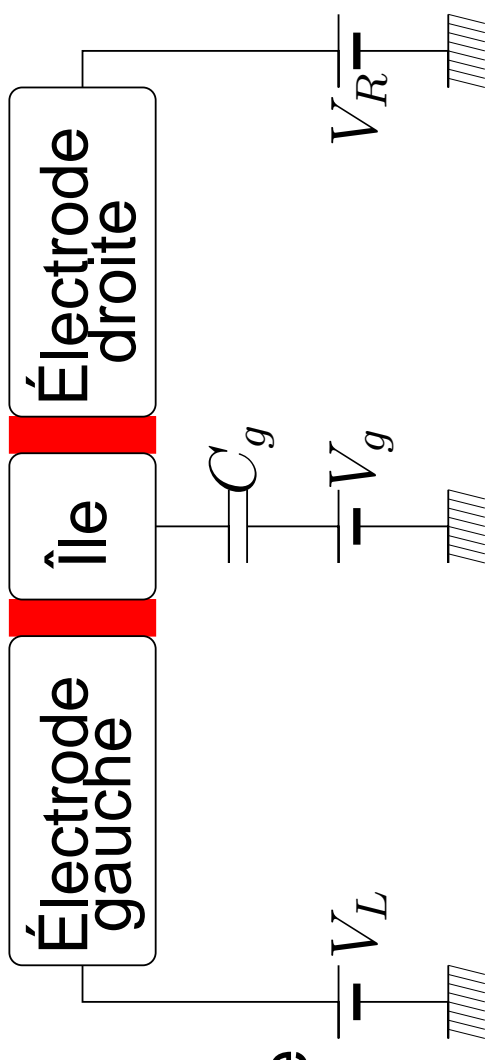
$$L \simeq 1\mu m$$

$$E_c \simeq 1K$$

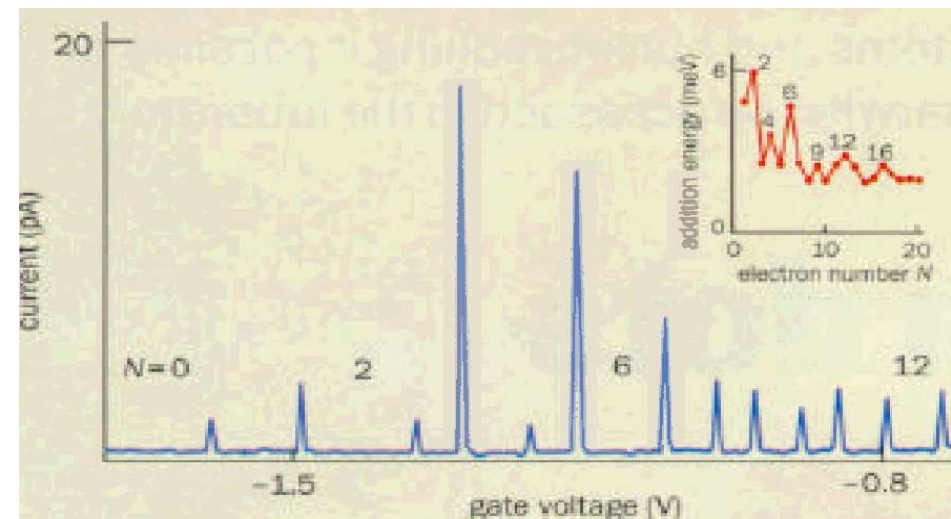
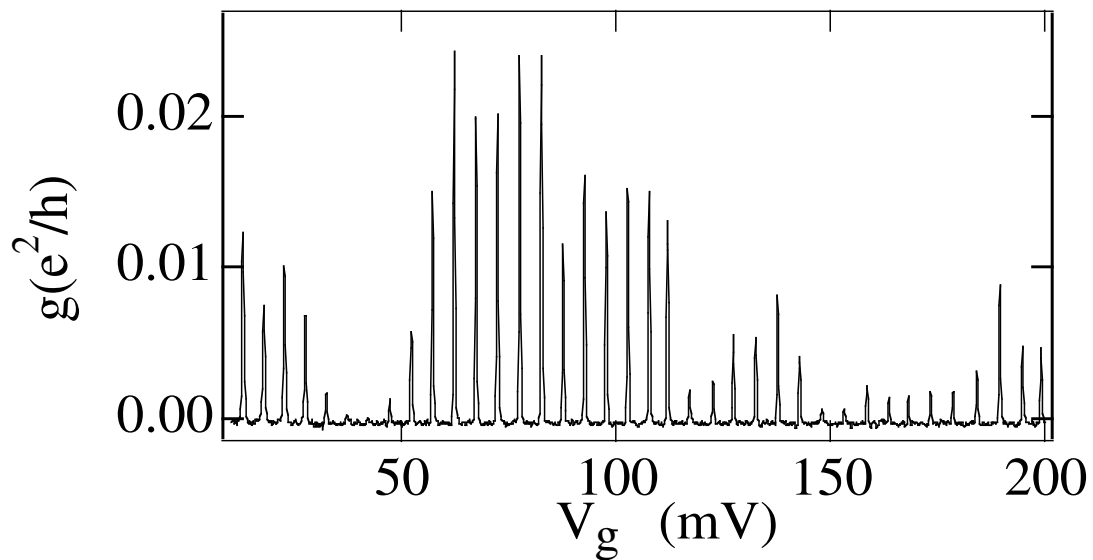
Île métallique

Couches d'oxyde
Électrode gauche
Île
Électrode droite
Substrat

G_L, C_L G_R, C_R

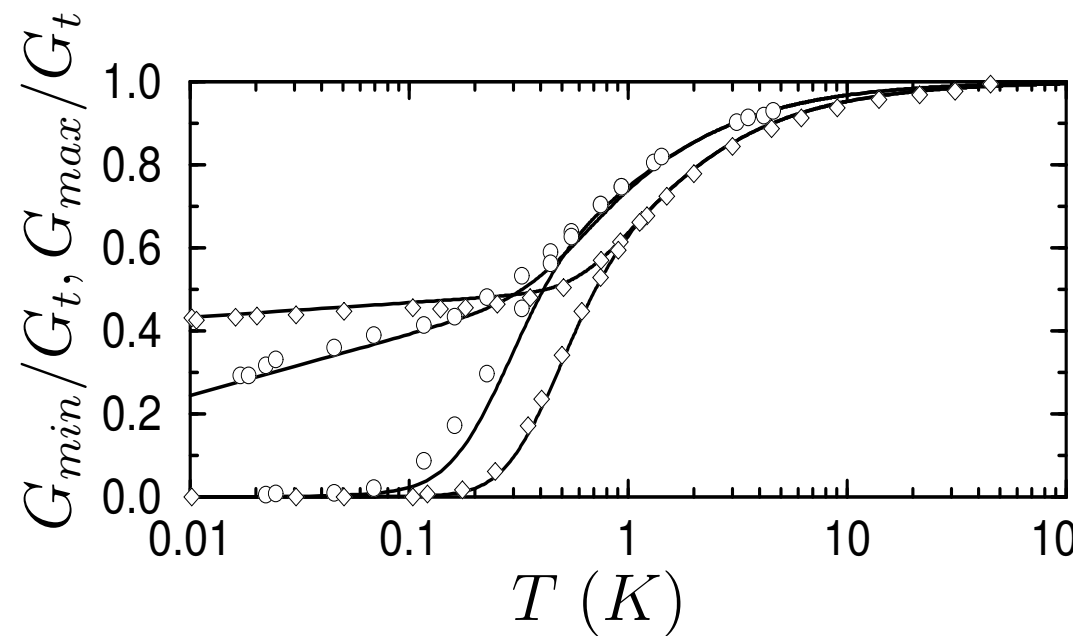
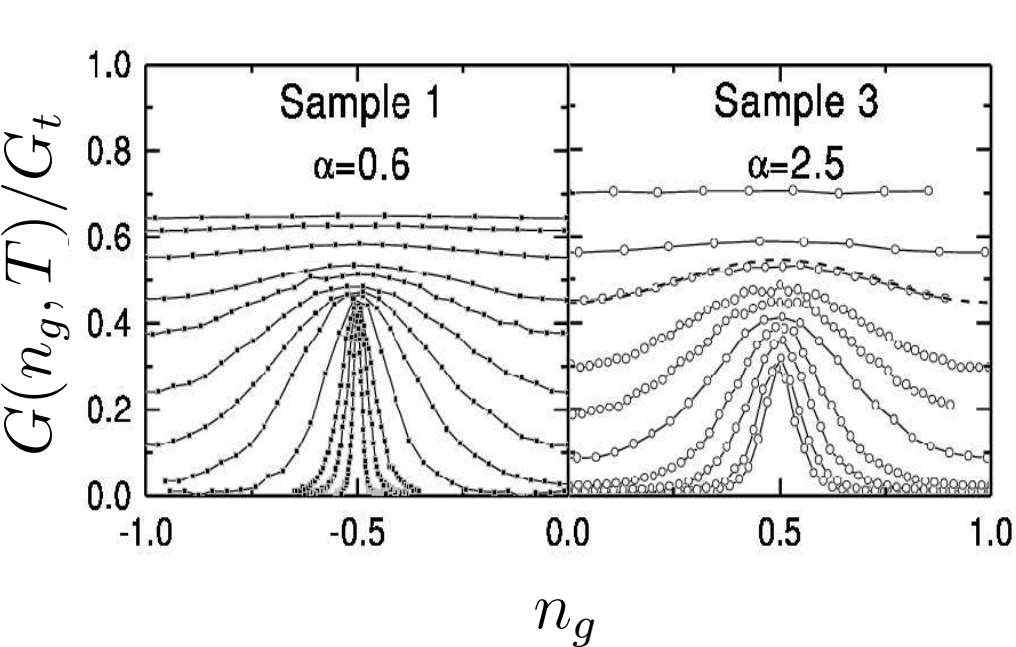


Blocage de Coulomb



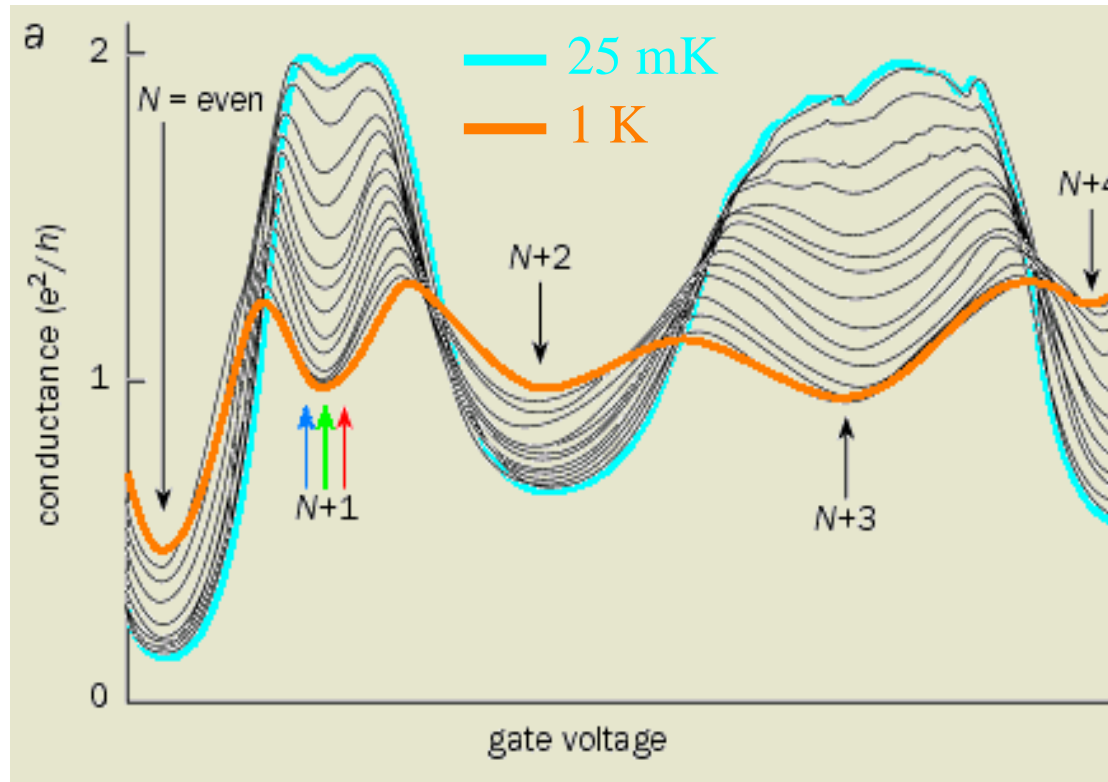
$$H(Q) = E_c Q^2 - eV_g Q$$

Couplage aux réservoirs



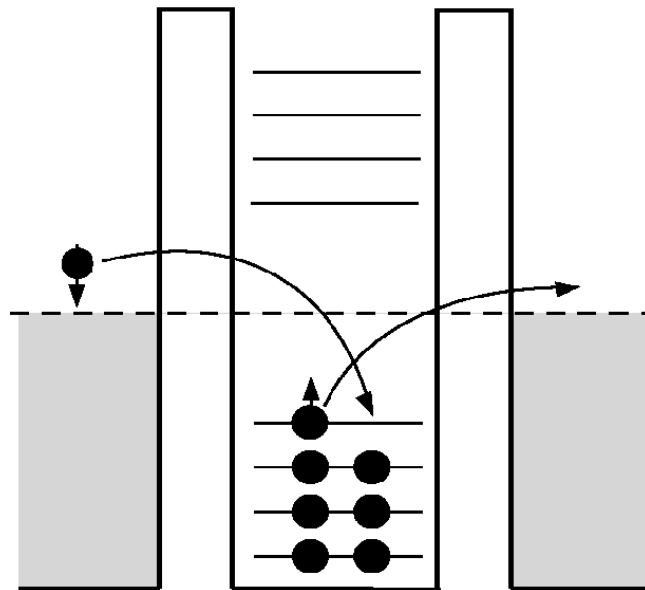
$$E_c^* < E_c$$

Effet Kondo



$$G \simeq \frac{e^2}{h}$$

Interprétation



Levée de dégénérescence

Resonance Kondo à ϵ_F

Modèle

$$H = \sum_{k\sigma} \epsilon_k a_{k\sigma}^\dagger a_{k\sigma} + \sum_{p\sigma} \epsilon_p d_{p\sigma}^\dagger d_{p\sigma} + E_c \left(\sum_{p\sigma} d_{p,\sigma}^\dagger d_{p,\sigma} - n_g \right)^2 + \sum_{k\sigma p} \frac{t}{\sqrt{N_L}} (a_{k\sigma}^\dagger d_{p\sigma} + d_{p\sigma}^\dagger a_{k\sigma})$$

$$\circ \sigma = 1 \dots \mathcal{N}$$

$$\circ p = 1 \dots N_L$$

Difficultés

- ⑥ Modèle d'Anderson si $T \ll \delta E$: point quantique (régime Kondo)
- ⑥ Théorie effective si $\mathcal{N} \gg 1$: île métallique
- ⑥ Approche globale ?

Représentation de phase

$$E_c \left(\sum_{p\sigma} d_{p,\sigma}^\dagger d_{p,\sigma} \right)^2 = E_c \hat{L}^2$$

$$d_{p,\sigma}^\dagger = f_{p,\sigma}^\dagger e^{i\theta}$$

$$Q = \sum_{p\sigma} d_{p,\sigma}^\dagger d_{p,\sigma} = \hat{L} = \frac{1}{i} \frac{\partial}{\partial \theta}$$

Action exacte

$$S = \int_0^\beta d\tau \sum_{p\sigma} f_{p\sigma}^\dagger (\partial_\tau + \epsilon_p - \delta\mu) f_\sigma + \frac{(\partial_\tau \theta + i\delta\mu)^2}{4E_c} + in_g \partial_\tau \theta$$
$$+ \int_0^\beta d\tau \int_0^\beta d\tau' \frac{1}{N_L} \Delta(\tau - \tau') \sum_{pp'\sigma} f_{p\sigma}^\dagger(\tau) f_{p'\sigma}(\tau') e^{i\theta(\tau) - i\theta(\tau')}$$

$$\Delta(i\omega) = \sum_k \frac{t^2}{i\omega - \epsilon_k} \simeq -it^2 D(0) \equiv -i\Gamma$$

Intégration perturbative des fermions:

$$S = \int_0^\beta d\tau \frac{(\partial_\tau \theta)^2}{4E_c} + i n_g \partial_\tau \theta - \int_0^\beta d\tau \int_0^\beta d\tau' \alpha(\tau - \tau') e^{i\theta(\tau) - i\theta(\tau')}$$

$$\alpha(\tau) = \frac{\mathcal{N}\Gamma}{W} \frac{1}{\tau^2} \equiv \alpha_t \frac{1}{\tau^2}$$

Approche auto-cohérente

$$\int_0^\beta d\tau \int_0^\beta d\tau' \frac{1}{N_L} \Delta(\tau - \tau') \sum_{pp'\sigma} f_{p\sigma}^\dagger(\tau) f_{p'\sigma}(\tau') e^{i\theta(\tau) - i\theta(\tau')}$$

⇓

$$\int_0^\beta d\tau \int_0^\beta d\tau' \frac{1}{N_L} \Delta(\tau - \tau') \sum_{pp'\sigma} \langle f_{p\sigma}^\dagger(\tau) f_{p'\sigma}(\tau') \rangle e^{i\theta(\tau) - i\theta(\tau')} \\ + \int_0^\beta d\tau \int_0^\beta d\tau' \frac{1}{N_L} \Delta(\tau - \tau') \sum_{pp'\sigma} \langle e^{i\theta(\tau) - i\theta(\tau')} \rangle f_{p\sigma}^\dagger(\tau) f_{p'\sigma}(\tau')$$

Coulomb et Kondo

- ⑥ Îles: exact à $\mathcal{N} \gg 1$
- ⑥ Points bloqués à $T \gg \delta E$
- ⑥ Effet Kondo dans les points quantiques ($T \ll \delta E$): analogie NCA

$$X(\tau) \equiv e^{i\theta(\tau)}$$

$$G_X(i\nu_n) = \left[\frac{\nu_n^2}{2E_c} + \lambda - \Sigma_X(i\nu_n) \right]^{-1}$$

$$G_X(\tau = 0) = 1$$

$$G_f^{loc}(i\omega_n) = \left[\frac{1}{\frac{1}{N_L} \sum_p 1/(i\omega_n - \epsilon_p)} - \Sigma_f(i\omega_n) \right]^{-1}$$

$$\Sigma_X(\tau) = \mathcal{N} \Delta(\tau) G_f^{loc}(\tau)$$

$$\Sigma_f(\tau) = \Delta(\tau) G_X(\tau)$$

$$\Delta(i\omega_n) = \sum_k t^2 / (i\omega_n - \epsilon_k) \sim -i\Gamma$$

Blocage de Coulomb ($T \gg \delta E$):

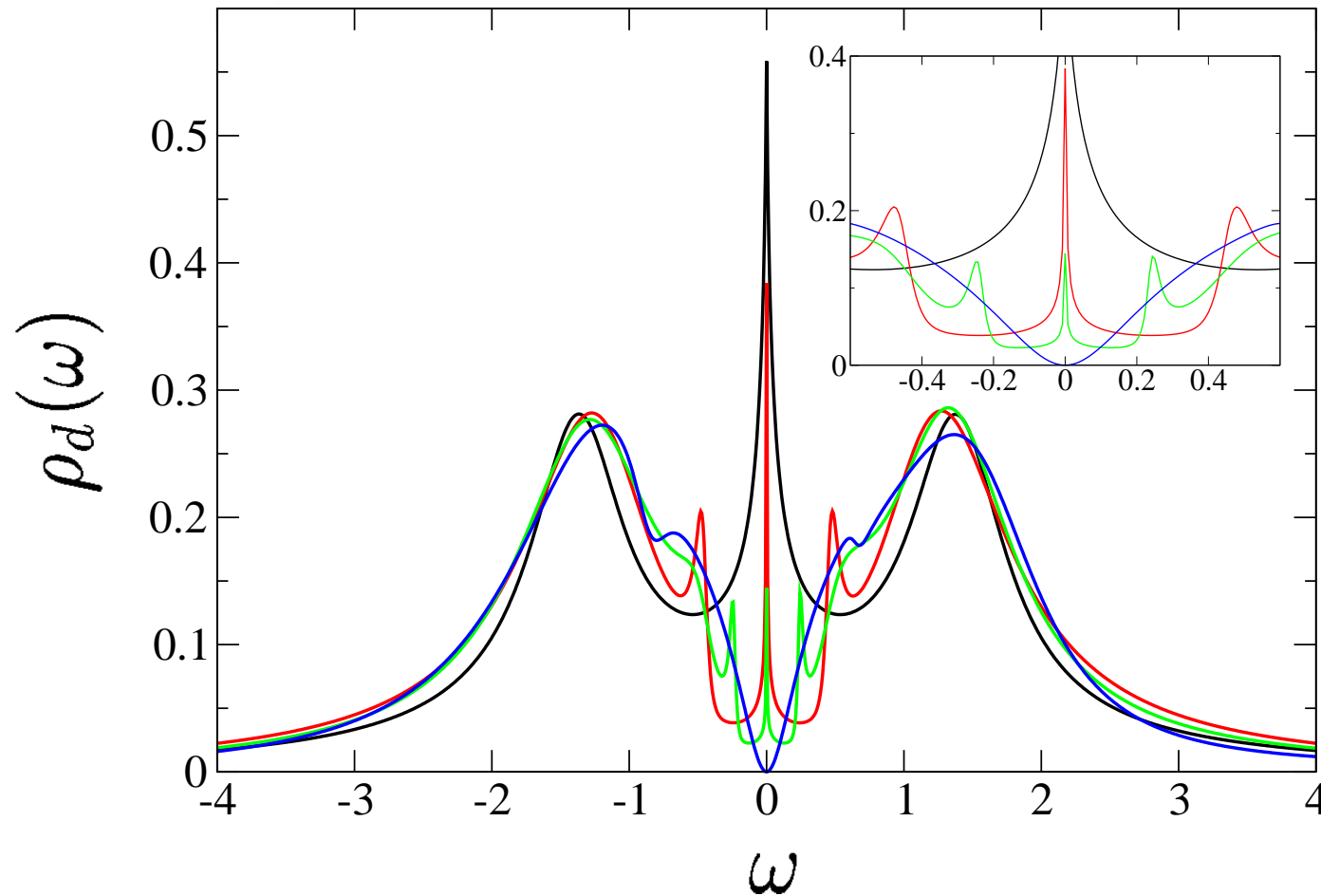
$$\circ E_c^* \sim \lambda \sim E_c e^{-2\pi^2 \alpha t}$$

Effet Kondo ($T \ll \delta E$):

$$\circ \text{Règle de Friedel: } \rho_d(\omega = T = 0) = \frac{1}{\pi\Gamma}$$

$$\circ T_K \sim \sqrt{\Gamma E_c} e^{-\frac{\pi E_c N_L}{4 \Gamma}}$$

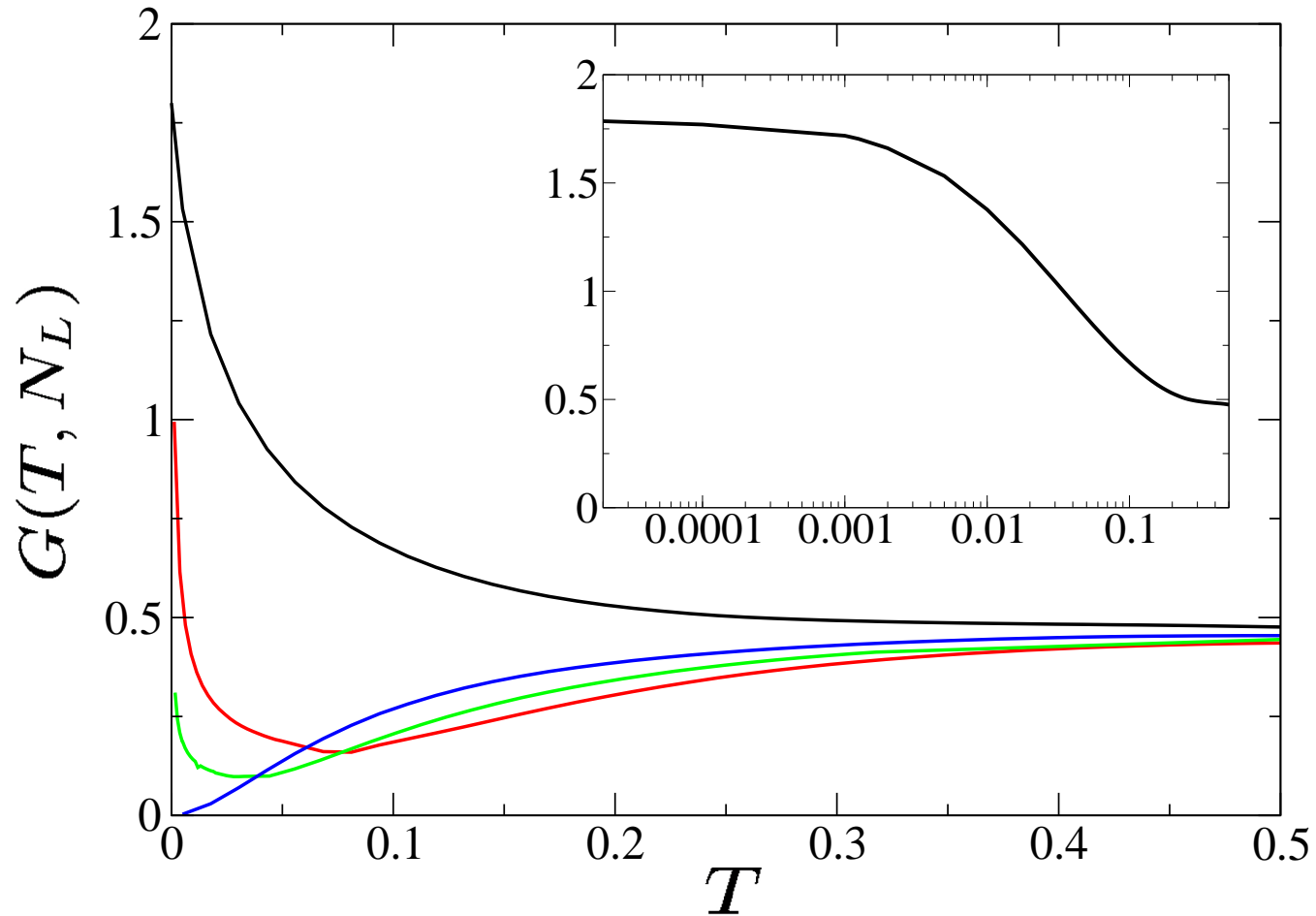
Illustration



$$W = \delta E (N_L - 1) \text{ fixé}$$

$$\text{Ici: } N_L = 1, 3, 5, \infty$$

Conductance



E_c^* et T_K

Limite dégénérée

$$\epsilon_p = 0 \quad \forall p = 1 \dots N_L$$

Modèle effectif à un niveau:

$$c_{1\sigma}^\dagger = \frac{1}{\sqrt{N_L}} \sum_{p=1}^{N_L} d_{p\sigma}^\dagger$$

$$T_K \sim \sqrt{\Gamma E_c} e^{-\frac{\pi E_c}{4 \Gamma}}$$

Cas $W \ll E_c, \Gamma$

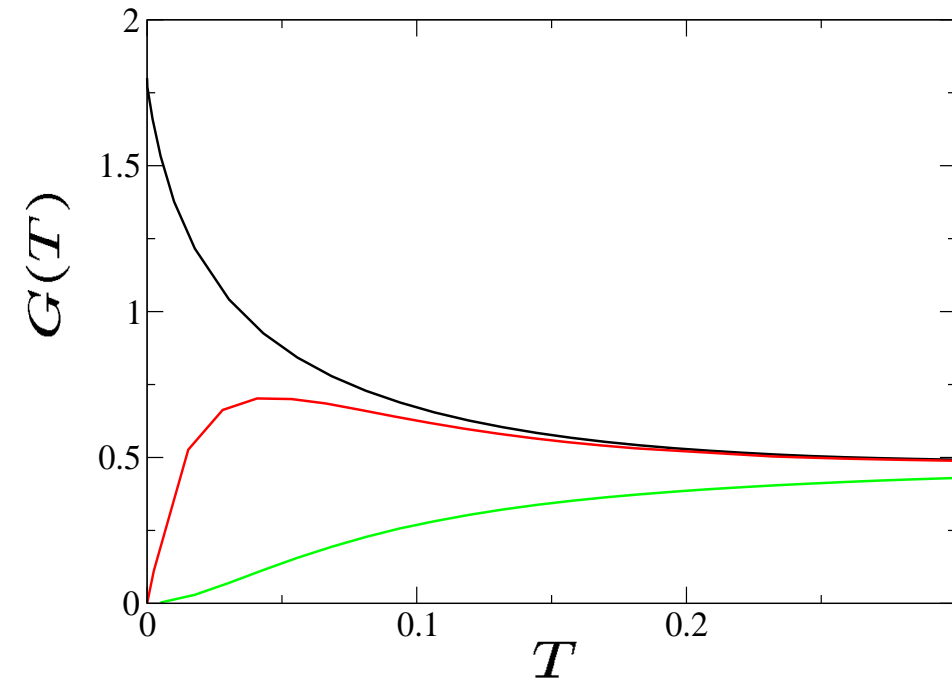
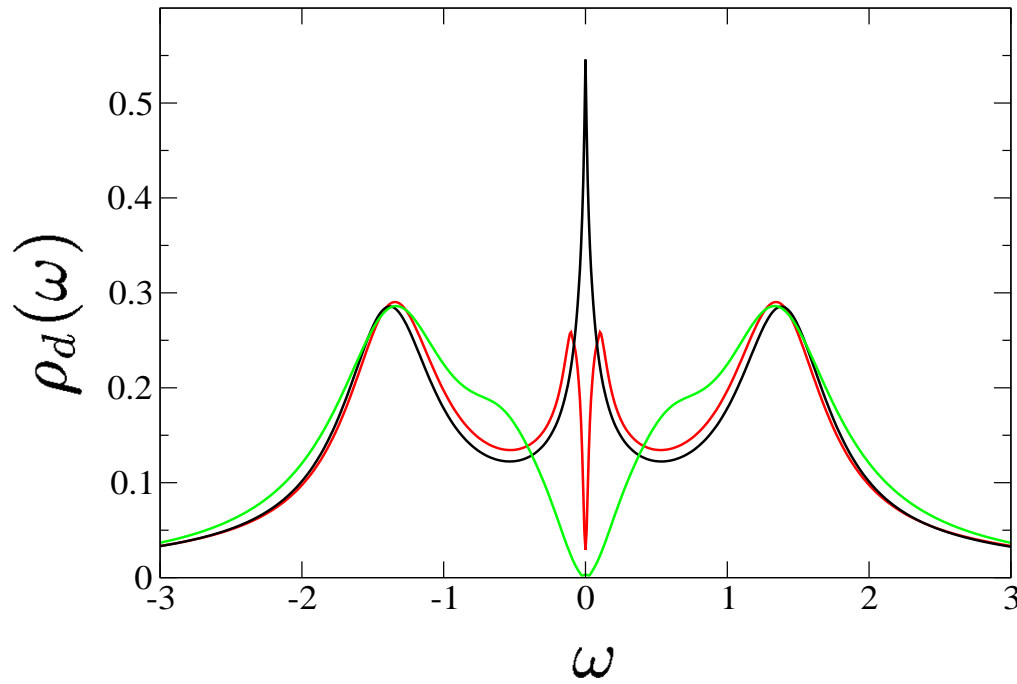
⑥ Conductance forte: $\alpha_t \propto \frac{\Gamma}{W} \gg 1$

⑥ Régime particulier:

$$E_c^* \sim e^{-2\pi^2\alpha_t} \ll T_K \sim e^{-\frac{\pi E_c}{4\Gamma}}$$

⑥ Blocage de Coulomb à $T = 0$

Illustration



$N_L = 21$ fixé et $W = 0, 0.2, 1$

Conclusion

- ⑥ Schéma unique pour décrire blocage de Coulomb et effet Kondo
- ⑥ Meilleure solution du problème de phase ?
- ⑥ Application aux milieux granulaires (DMFT)