The Suppression of Kondo Resonance in Double Quantum Dot System

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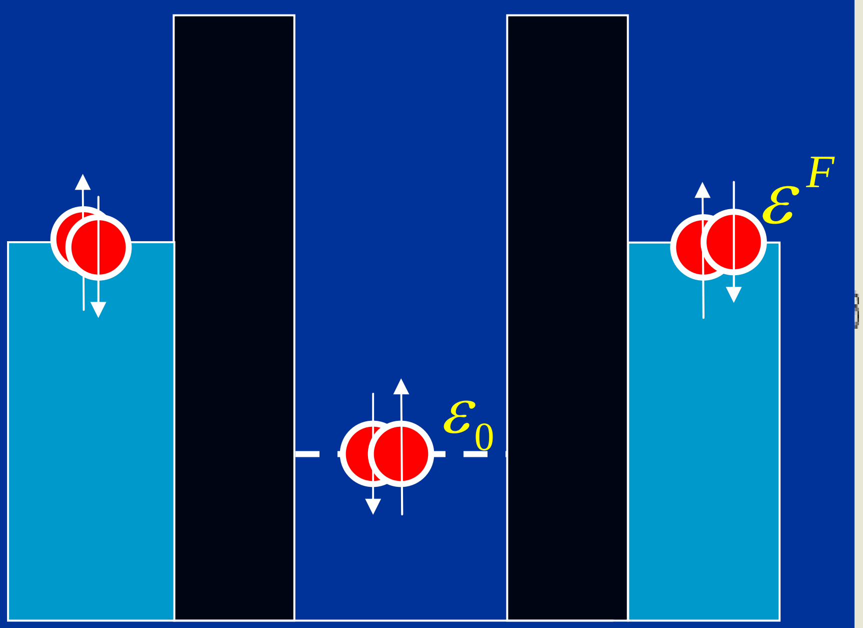
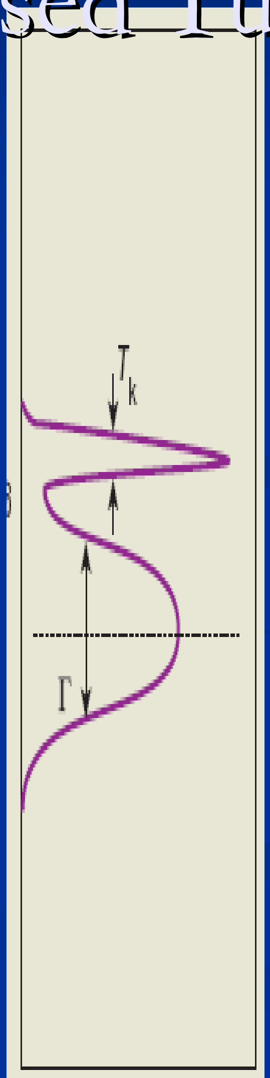
The Kondo Effect
and
Uncertainty Based Tunneling



Virtual State



$$\Delta t \approx (\Delta\varepsilon)^{-1} \approx \left(\varepsilon^F - \varepsilon_0\right)^{-1}$$

$$\left(\omega - \varepsilon_0 - \Sigma_T - \mathrm{K}\right) G^r_{\sigma\sigma} = 1 - \langle n_{\bar{\sigma}} \rangle$$

$$\mathrm{K} = \sum_k \frac{|V|^2}{\left(\omega - \varepsilon_{k,\bar{\sigma}}\right)} f_{k,\bar{\sigma}}$$

$$T_K = De^{-\frac{(\varepsilon_F - \varepsilon_0)}{\Gamma}}$$

Kondo effect and the Anderson impurity model

$$H = H_{lead} + H_{QD} + H_T$$

$$H_{lead} = \sum_{k\alpha,\sigma} V_{k_\alpha,\sigma} c^+_{k_\alpha,\sigma} d_\sigma + h.c.$$

$$H_{QD} = \sum_{\sigma} \varepsilon_\sigma d^+_\sigma d_\sigma + U n_\sigma n_{\bar{\sigma}}$$

$$H_T = \sum_{k\alpha,\sigma} V_{k_\alpha\sigma,\sigma} c^+_{k_\alpha,\sigma} d_\sigma + h.c.$$

$$H = H_{lead} + H_{ex} + H_{impurt}$$

$$H_K = \sum_{k,k'} J_{k,k'} \left\langle \phi^*_d \sigma \phi_d \right\rangle \bullet \left\langle \phi^*_{k'} S \phi_k \right\rangle$$

$$H_{lead} = \sum_{k,s} \varepsilon_{k,s} c^+_{k,s} c_{k,s}$$

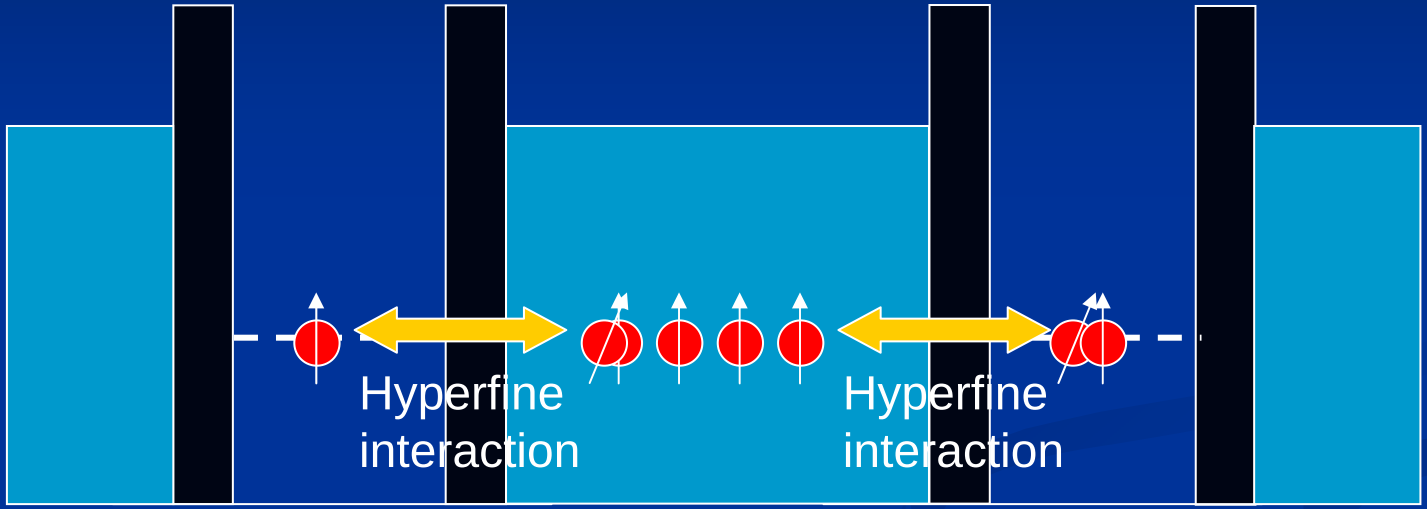
$$H_{impurt} = \sum_{k,\sigma} \varepsilon_\sigma d^+_\sigma d_\sigma$$

Schrieffer-Wolf Canonical Transport

The mechanism of the suppression of Kondo resonant peak in DQD system

- 1. The RKKY interaction
- 2. The coherent interdot transition

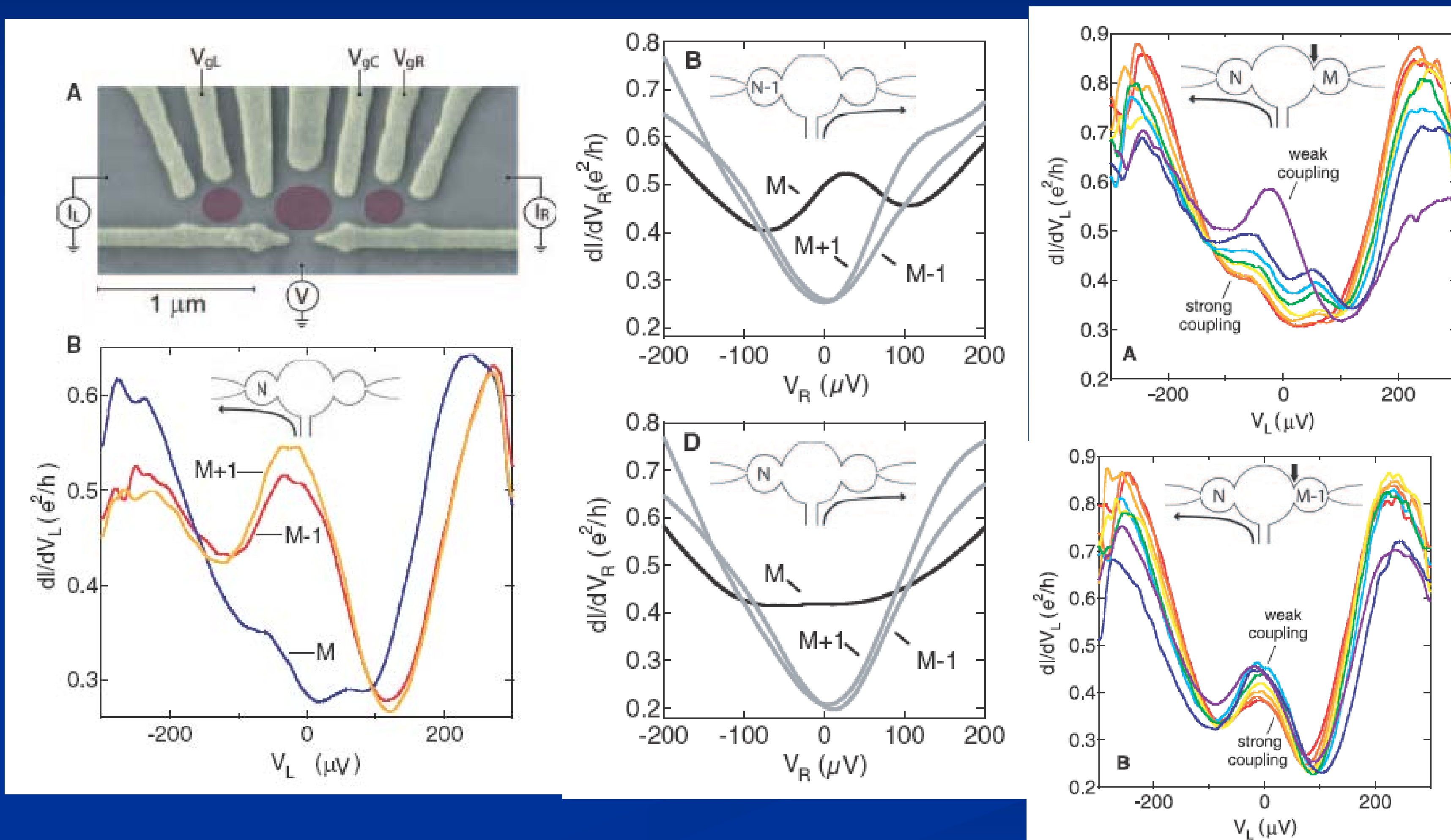
The RKKY effect



$$H_{RKKY} = \frac{J}{N} \sum_{\sigma\sigma'} d^{+}_{R\sigma} d_{L\sigma} d^{+}_{L\sigma'} d_{R\sigma'}$$

$$J \approx 4 \frac{V_C^2}{U_{\text{int}}}$$

The competition between the Kondo effect and the RKKY effect



The coherent interdot transition

(PHYSICAL REVIEW B **77**, 041305R 2008
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)

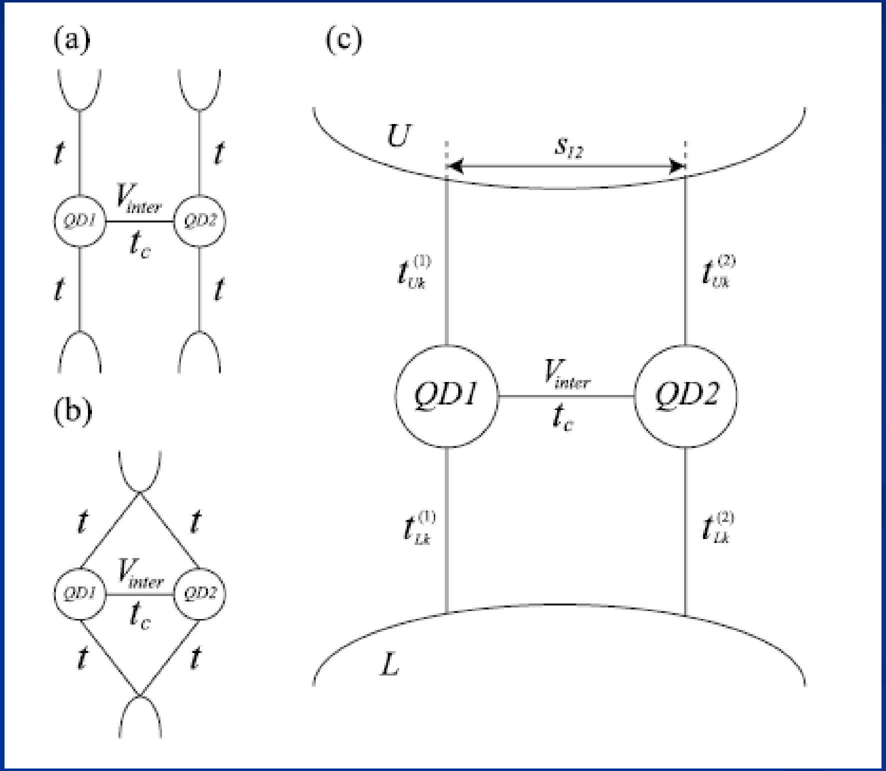
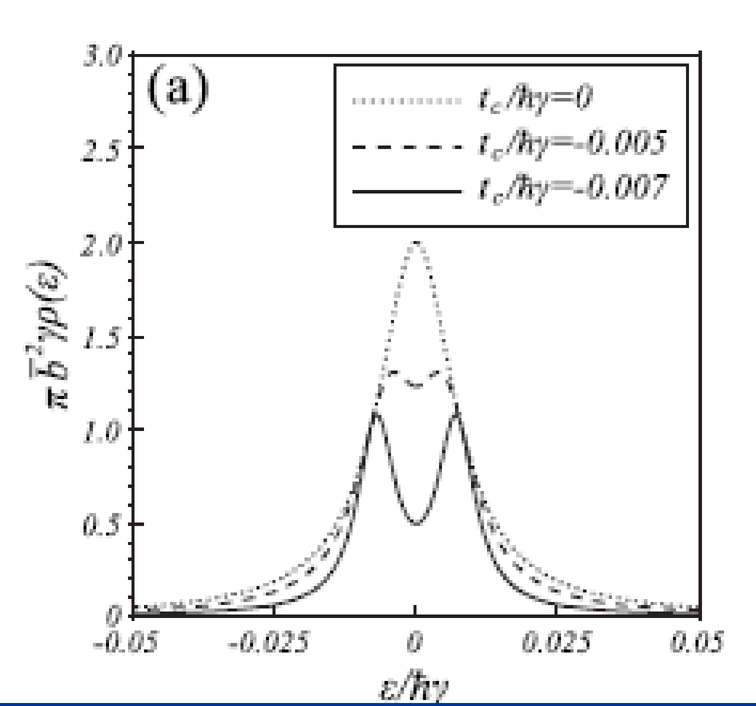
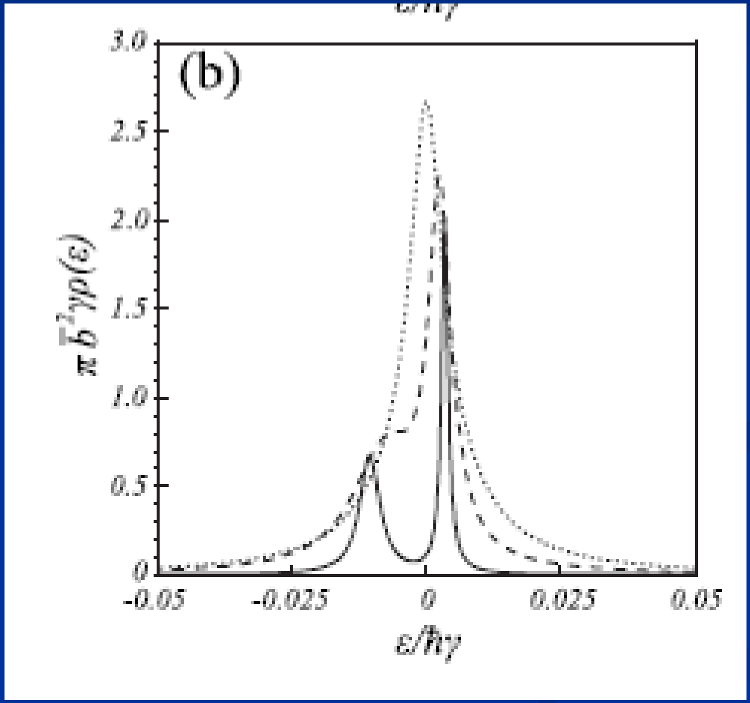


FIG. 1. Schematic diagrams of laterally coupled DQDs. (a) Two reservoirs are completely separated, namely, there is no tunneling process between the two QDs via the reservoirs. Here $\alpha=0$. (b) The electrons can tunnel indirectly only via a point in the reservoirs between the two QDs. Here $\alpha=1$. (c) $0<|\alpha|<1$. s_{12} is the minimum distance that electrons propagate in the reservoirs.



$\alpha = 0$

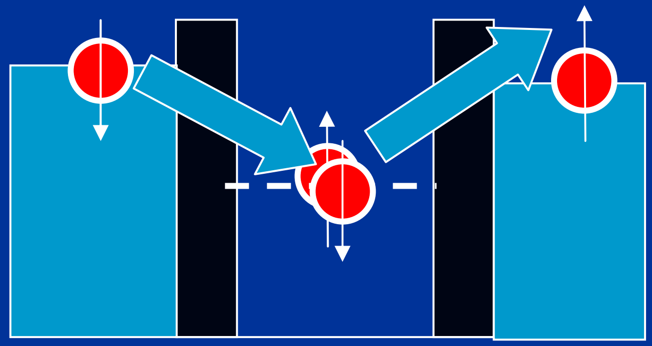


$\alpha = 0.5$

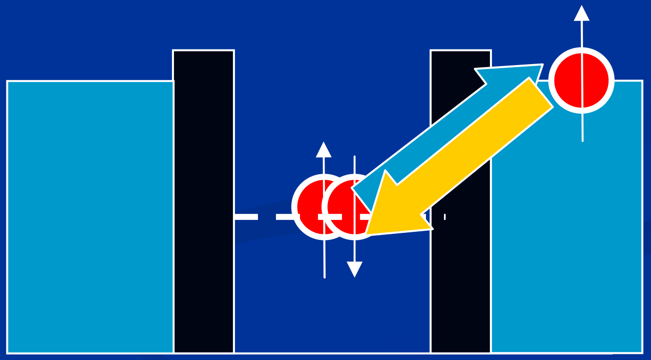
The Considered System

- 1. The single dot with spin flipping associated tunneling
- 2. The parallel coupled double-quantum-dot with coherent interdot transistion
- The infinite intra-dot Coulomb interaction approximation is adoptted, i.e., the RKKY interaction is ignored.

Spin flipping associated tunneling

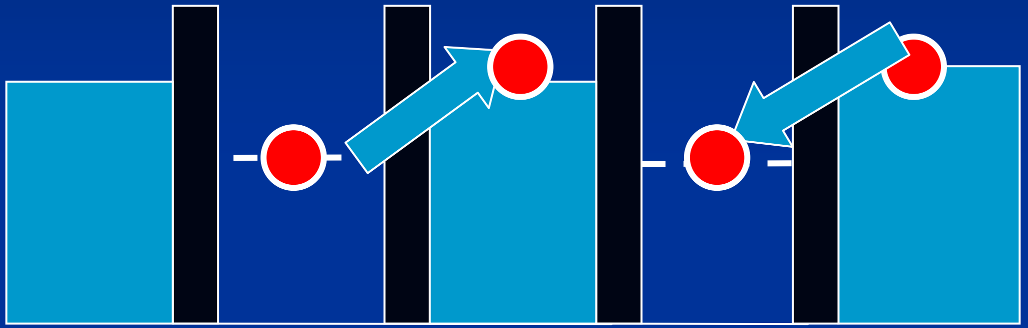


Direct normal tunneling

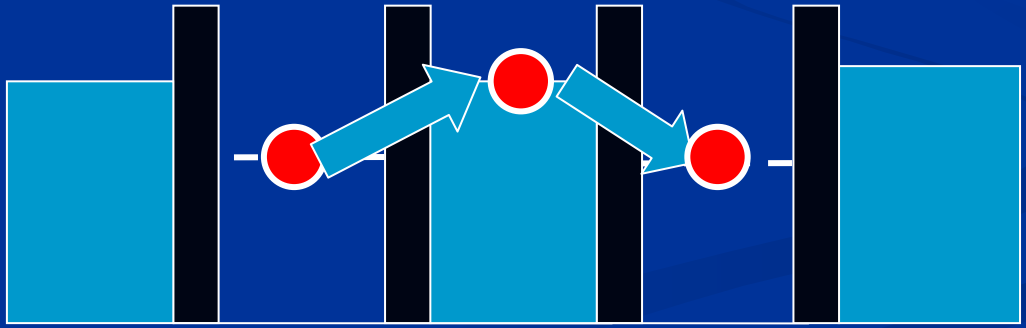


Spin-flipping associated tunneling

Coherent Interdot Transition



The incoherent interdot transition



The coherent interdot transition

Double Quantum Dot : The Pseudo-Spin System

$$H = H_{lead} + H_{QD} + H_T$$

$$H_{lead} = \sum_{k\alpha,\sigma} V_{k_\alpha,\sigma} c^{+}_{k_\alpha,\sigma} d_\sigma + h.c.$$

$$H_{QD} = \sum_{\sigma} \varepsilon_\sigma d^{+}_\sigma d_\sigma + U n_\sigma n_{\bar{\sigma}}$$

$$H_T = \sum_{k\alpha,\sigma} V_{k_\alpha\sigma,\sigma} c^{+}_{k_\alpha,\sigma} d_\sigma + V_{k_\alpha\sigma,\bar{\sigma}} c^{+}_{k_\alpha,\sigma} d_{\bar{\sigma}} + h.c.$$

Spin flipping associated Tunneling

$$H = H_{lead} + H_{DQD} + H_T$$

$$H_{lead} = \sum_{k\alpha,n} \varepsilon_{k_\alpha,n} c^{+}_{k_\alpha,n} c_{k_\alpha,n} + h.c.$$

$$H_{DQD} = \sum_{m} \varepsilon_m d^{+}_m d_m + U n_1 n_2$$

$$H_T = \sum_{k\alpha,m,n} V_{k_\alpha n,m} c^{+}_{k_\alpha,n} d_m + V_{k_\alpha n,\bar{m}} c^{+}_{k_\alpha,n} d_{\bar{m}} + h.c.$$

Coherent interdot transition

The EOM Solution

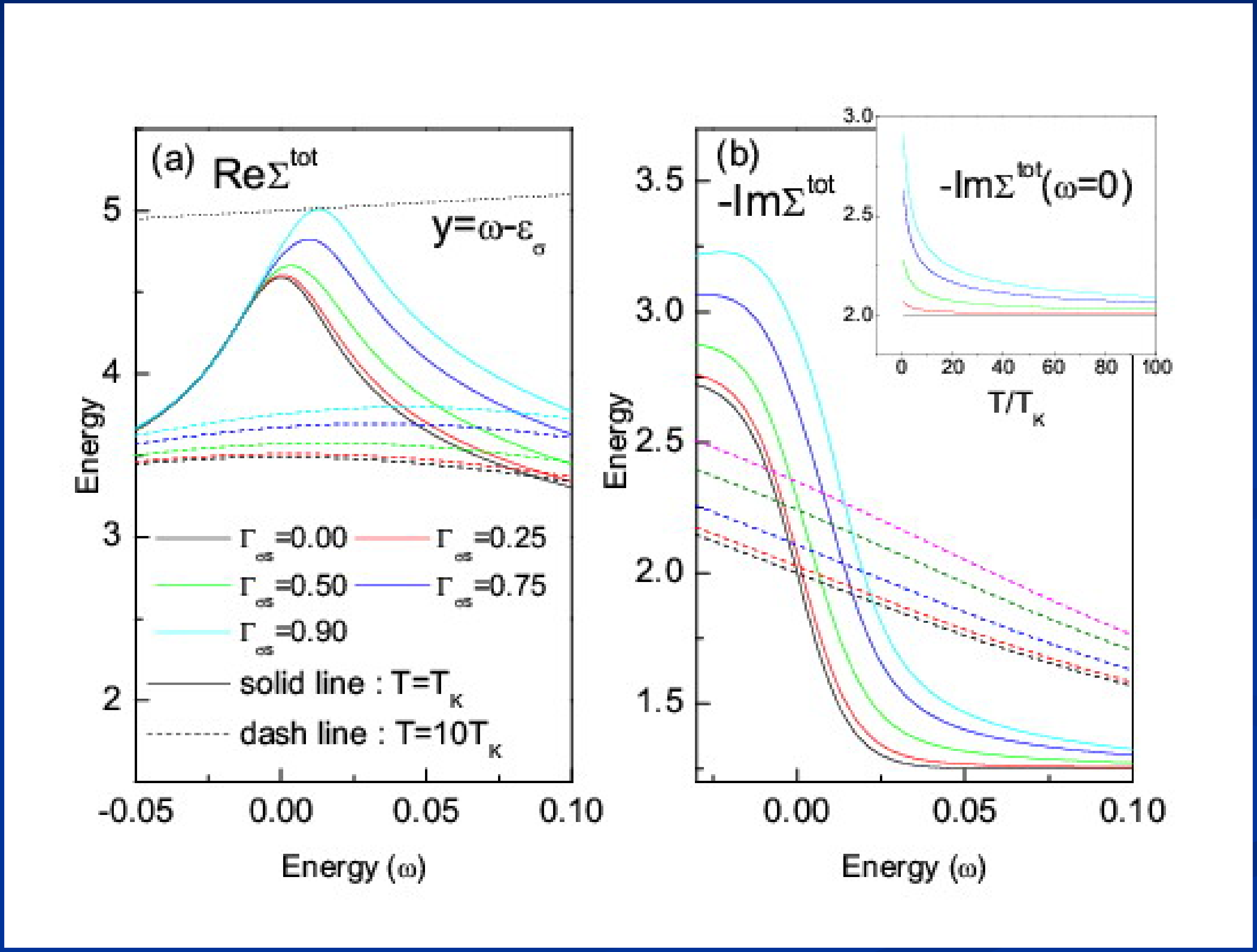
$$\begin{pmatrix} G_{mm} & G_{m\bar{m}} \\ G_{\bar{m}m} & G_{\bar{m}\bar{m}} \end{pmatrix} = \begin{pmatrix} \left(1-\langle n_{\bar{m}}\rangle\right)\left[\left(\tilde{G}^{0}_{mm}\right)^{-1} - \Sigma^{tot}_{m\bar{m}}\tilde{G}^{0}_{mm}\Sigma^{tot}_{\bar{m}m}\right] & \tilde{G}^{0}_{mm}\Sigma^{tot}_{\bar{m}m}G_{\bar{m}\bar{m}} \\ \tilde{G}^{0}_{\bar{m}\bar{m}}\Sigma^{tot}_{\bar{m}m}G_{mm} & \left(1-\langle n_{m}\rangle\right)\left[\left(\tilde{G}^{0}_{\bar{m}\bar{m}}\right)^{-1} - \Sigma^{tot}_{\bar{m}m}\tilde{G}^{0}_{\bar{m}\bar{m}}\Sigma^{tot}_{m\bar{m}}\right] \end{pmatrix}$$

$$\tilde{G}^{0}_{mm} \equiv \left(\omega - \varepsilon_m - \Sigma^{tot}_{mm}\right)$$

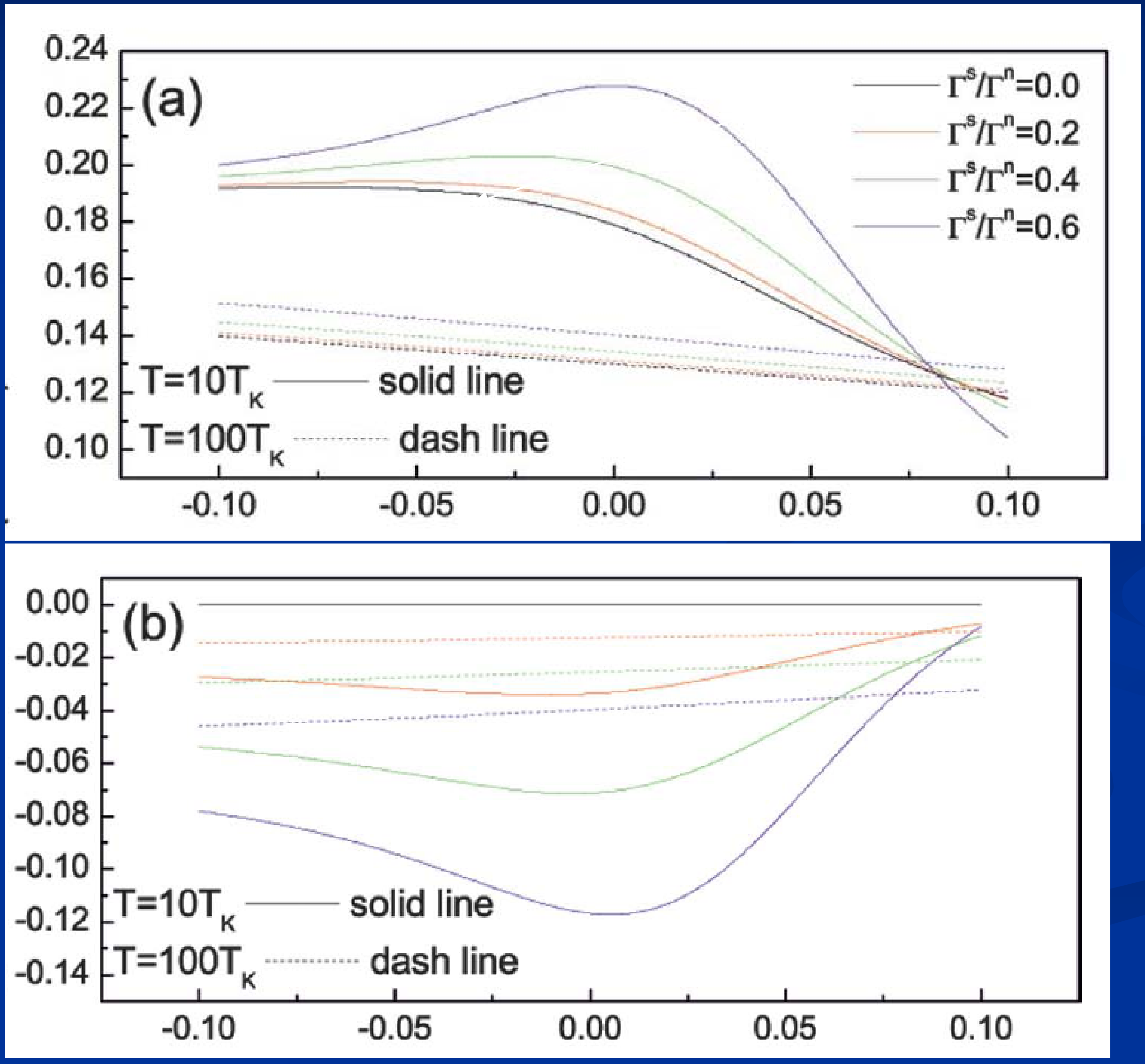
$$\Sigma^{tot}_{mm} \equiv \left(-\frac{\Gamma_n}{2}\right) + \sum_{k_\alpha,s}\left\langle d^{+}_{\bar{m}}d_m\right\rangle \frac{V^{*}_{k_\alpha s,m}V_{k_\alpha s,\bar{m}}}{\omega-\varepsilon_{k_\alpha s}} - \frac{\left|V_{k_\alpha s,\bar{m}}\right|^2}{\omega-\varepsilon_{k_\alpha s}-\varepsilon_m+\varepsilon_{\bar{m}}} f_\alpha\left(\varepsilon_{k_\alpha s}\right)$$

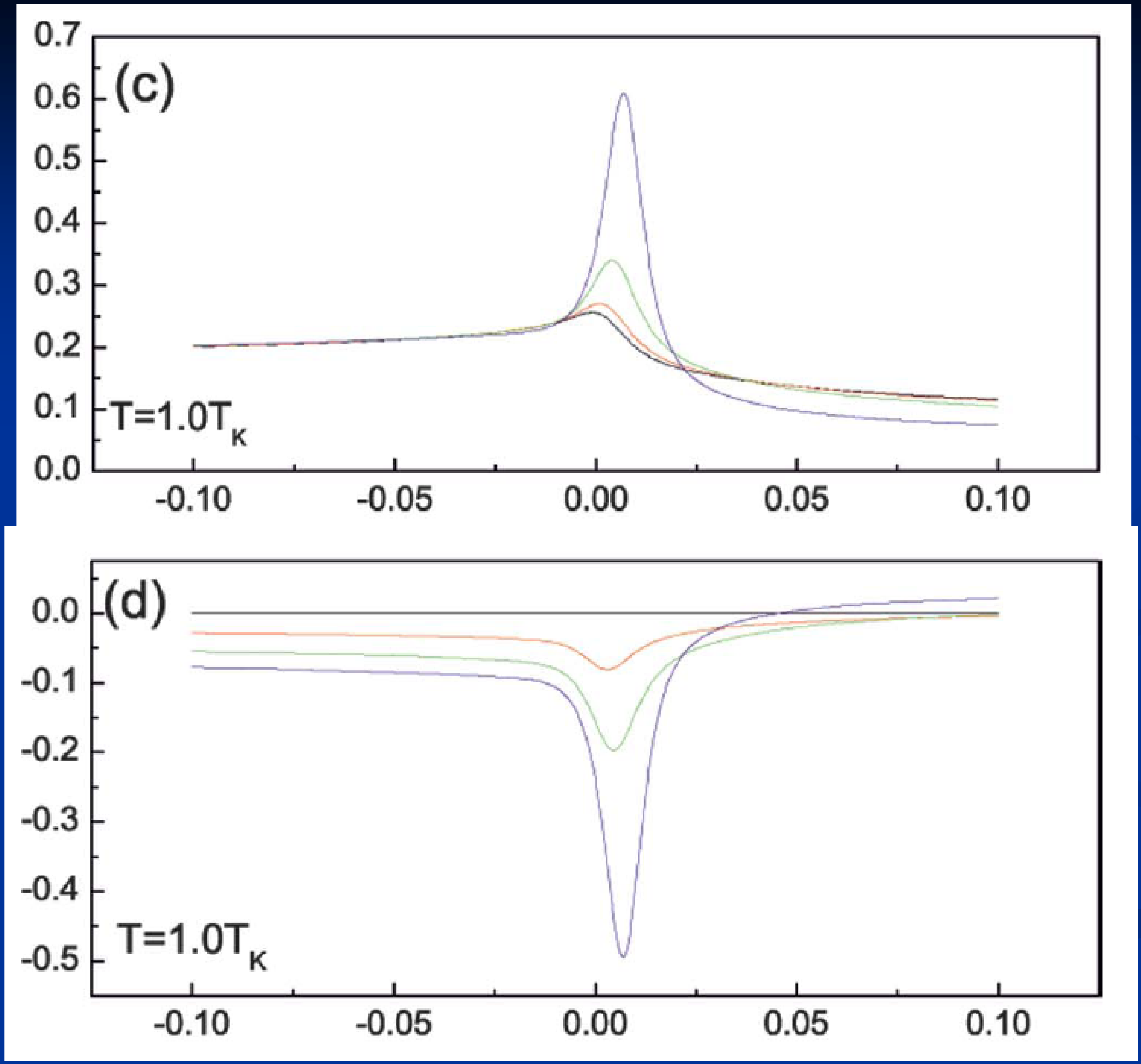
$$\Sigma^{tot}_{m\bar{m}} \equiv \left(-\frac{\Gamma_s}{2}\right) + \sum_{k_\alpha,s} -\left\langle n_{\bar{m}}\right\rangle \frac{V^{*}_{k_\alpha s,m}V_{k_\alpha s,\bar{m}}}{\omega-\varepsilon_{k_\alpha s}} + \frac{V^{*}_{k_\alpha s,m}V_{k_\alpha s,\bar{m}}}{\omega-\varepsilon_{k_\alpha s}} f_\alpha\left(\varepsilon_{k_\alpha s}\right)$$

The Self-energy

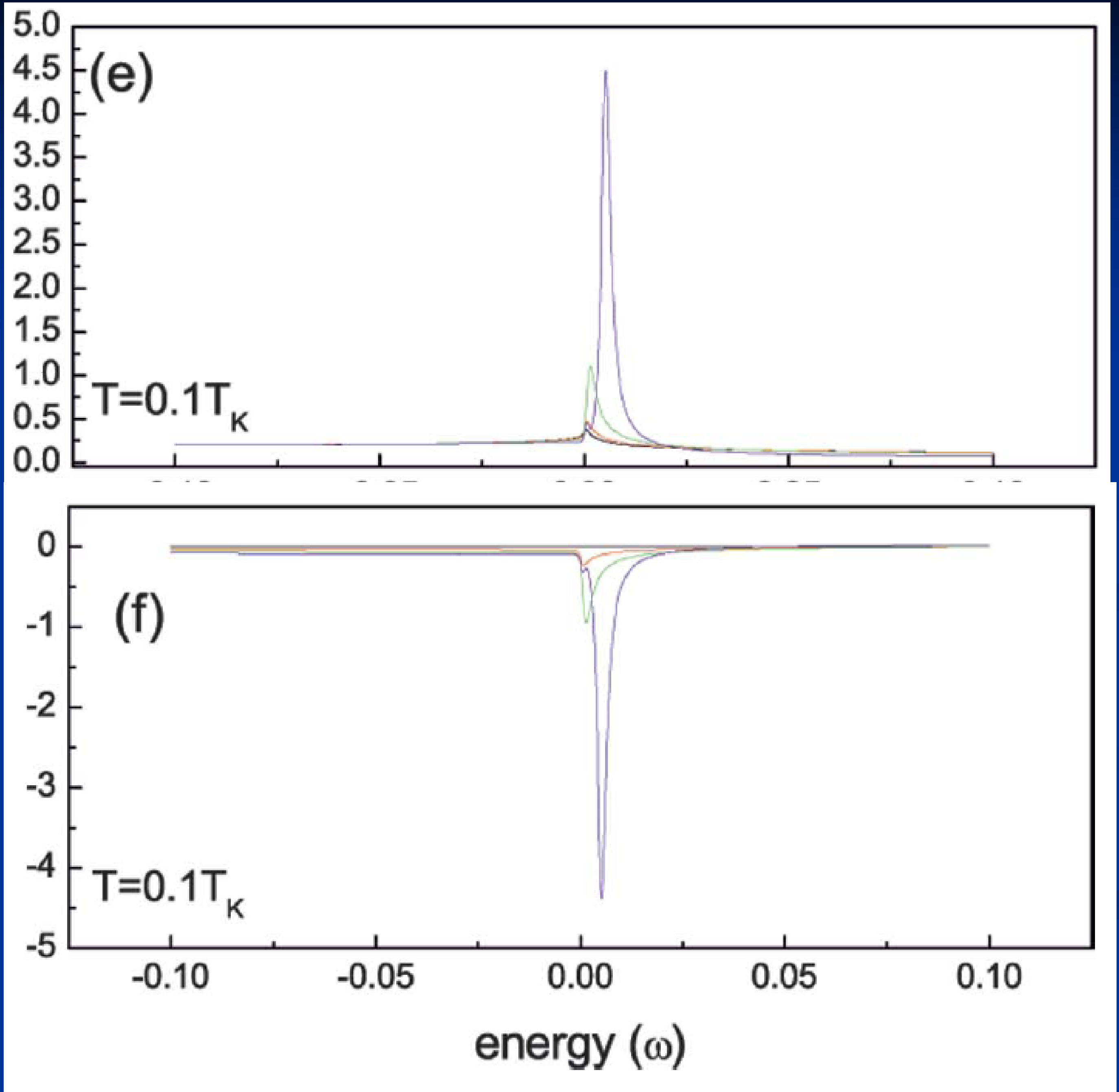


Spectral function



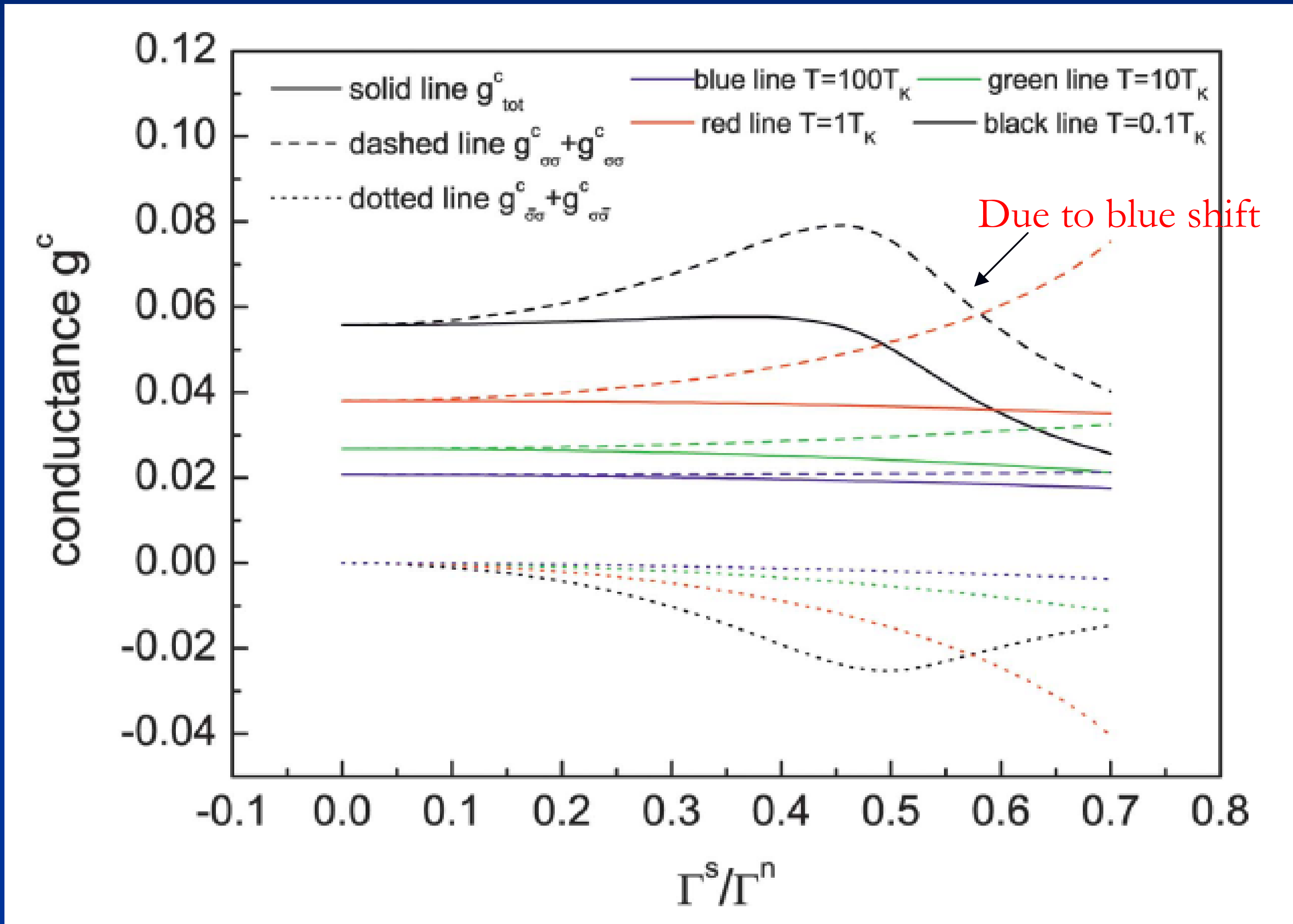


(c)
T=1.0T_K
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.10
-0.05
0.00
0.05
0.10
(d)
T=1.0T_K
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.10
-0.05
0.00
0.05
0.10

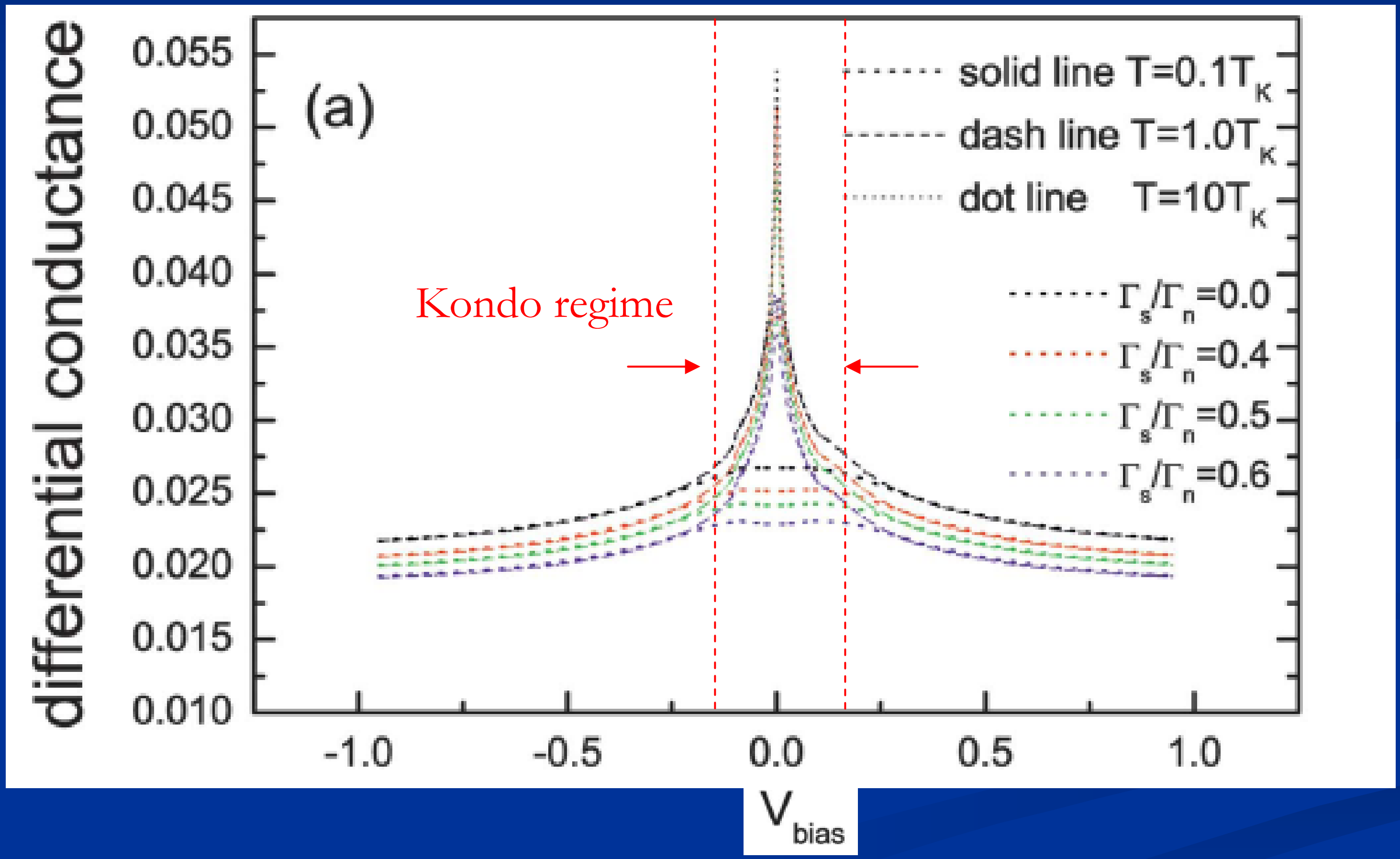


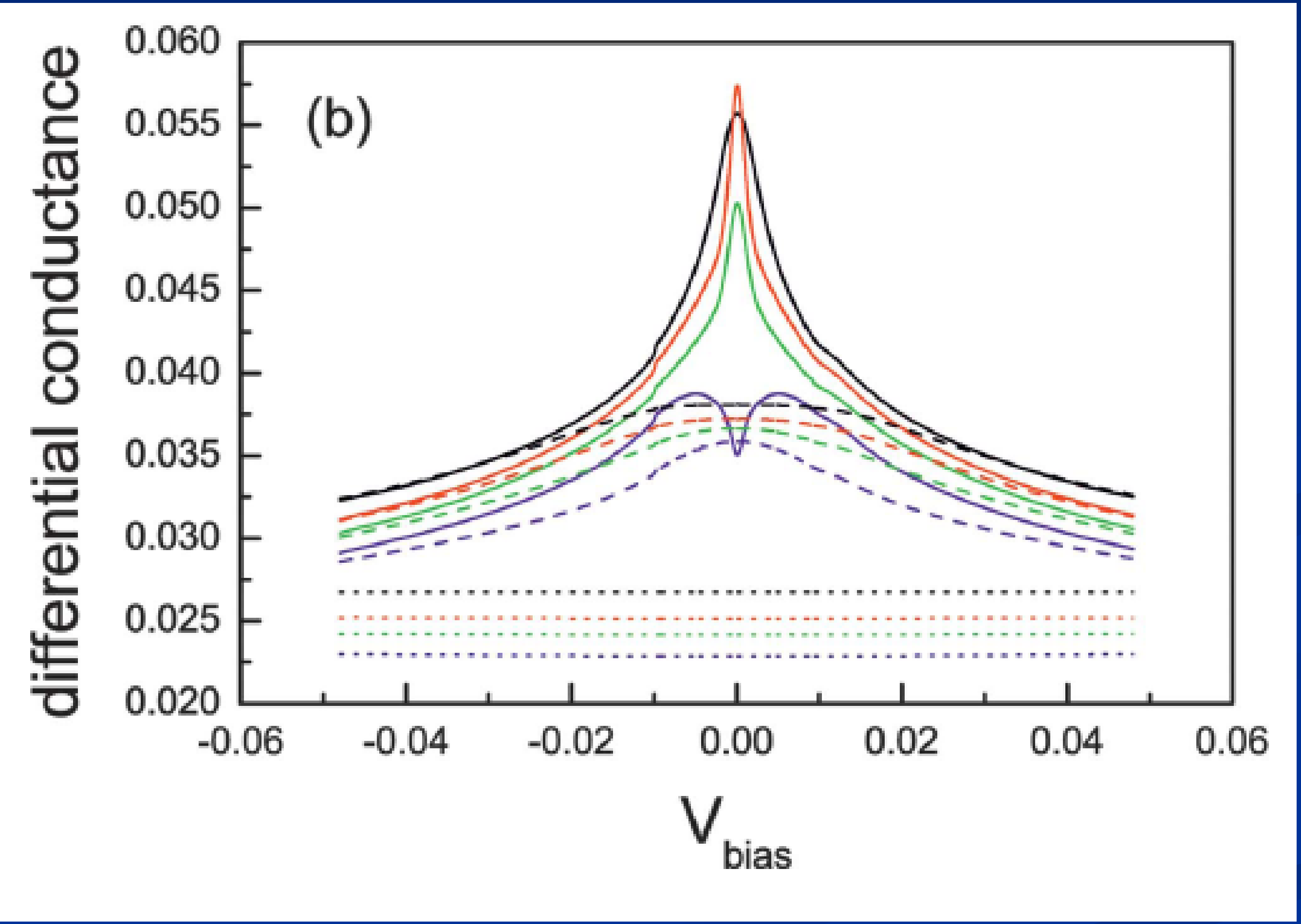
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(e)
T=0.1T$_K$
0
-1
-2
-3
-4
-5
(f)
T=0.1T$_K$
-0.10
-0.05
0.00
0.05
0.10
energy (ω)

The linear response Conductance



The finite bias conductance





(b)
differential conductance
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
-0.06
-0.04
-0.02
0.00
0.02
0.04
0.06
V bias

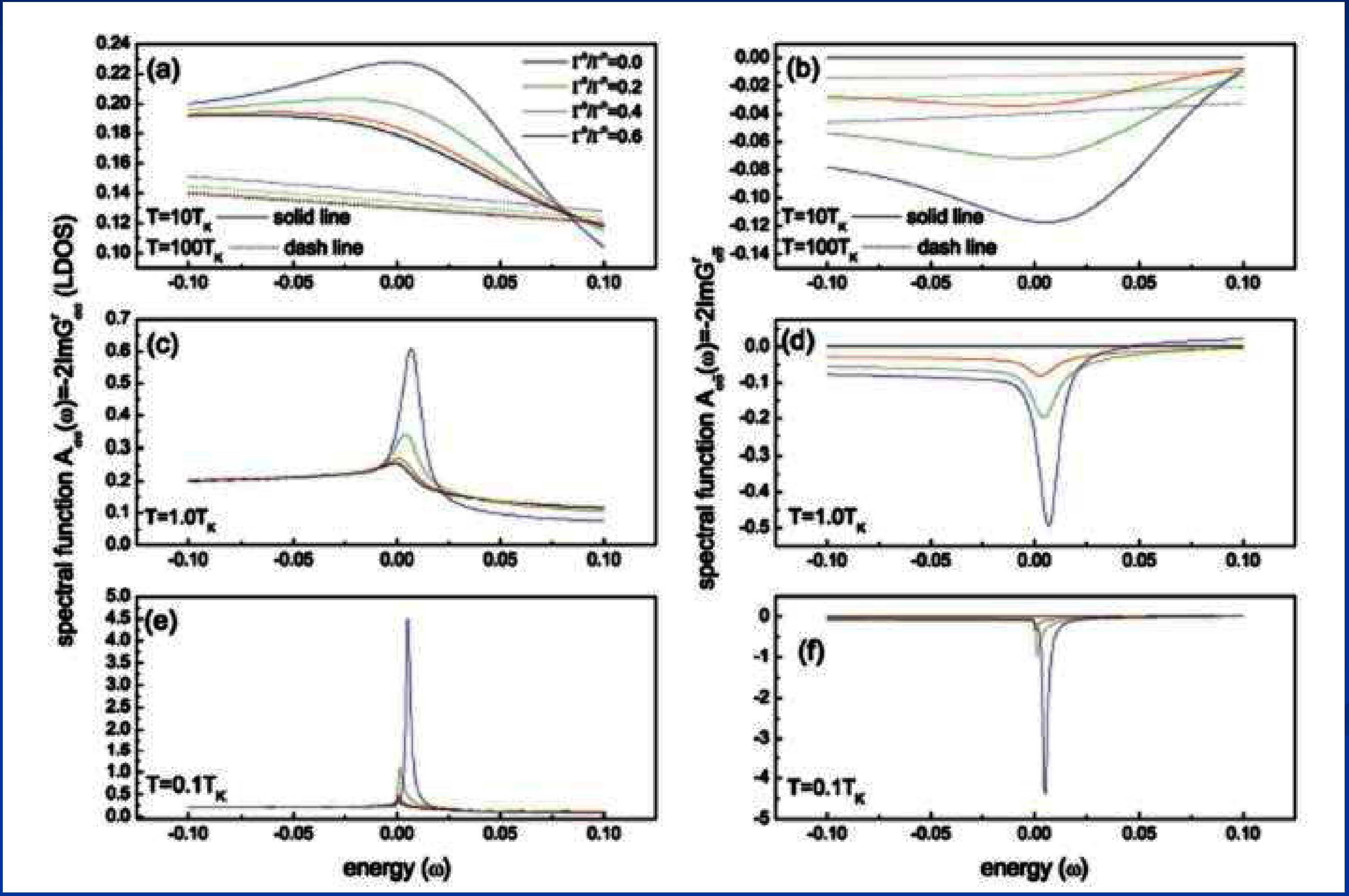
The effects due to the spin flipping associated tunneling (coherent interdot transition)

- 1.The increases of the effect Kondo temperature
- 2.Suppresses the resonant peak and causes the blue shift of the peak due to the Kondo effect
- 3. Suppresses the couductance when the strength of the coherent interdot transition (spin associated tunneling) is strong
- ---Thank You

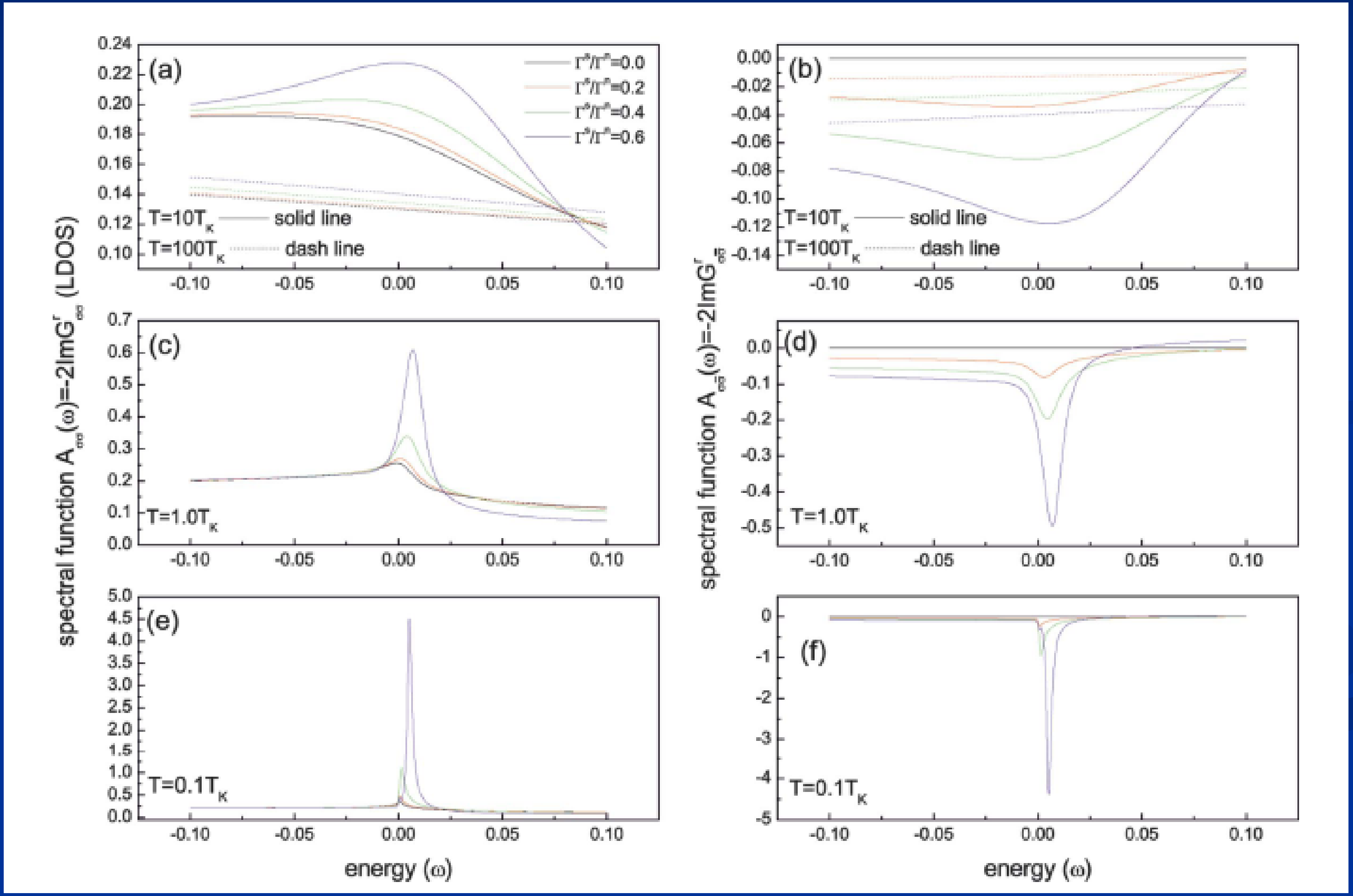
$$J = \frac{\mathrm{i}e}{\hbar} \int \frac{\mathrm{d}\varepsilon}{2\pi} [f_L(\varepsilon) - f_R(\varepsilon)] \mathcal{T}(\varepsilon) \ ,$$

$$\mathcal{T}(\varepsilon) = \mathrm{Tr} \left\{ \frac{\mathbf{\Gamma}^L(\varepsilon)\mathbf{\Gamma}^R(\varepsilon)}{\mathbf{\Gamma}^L(\varepsilon) + \mathbf{\Gamma}^R(\varepsilon)} [\mathbf{G}^{\mathrm{r}}(\varepsilon) - \mathbf{G}^{\mathrm{a}}(\varepsilon)] \right\} \ .$$

DOS

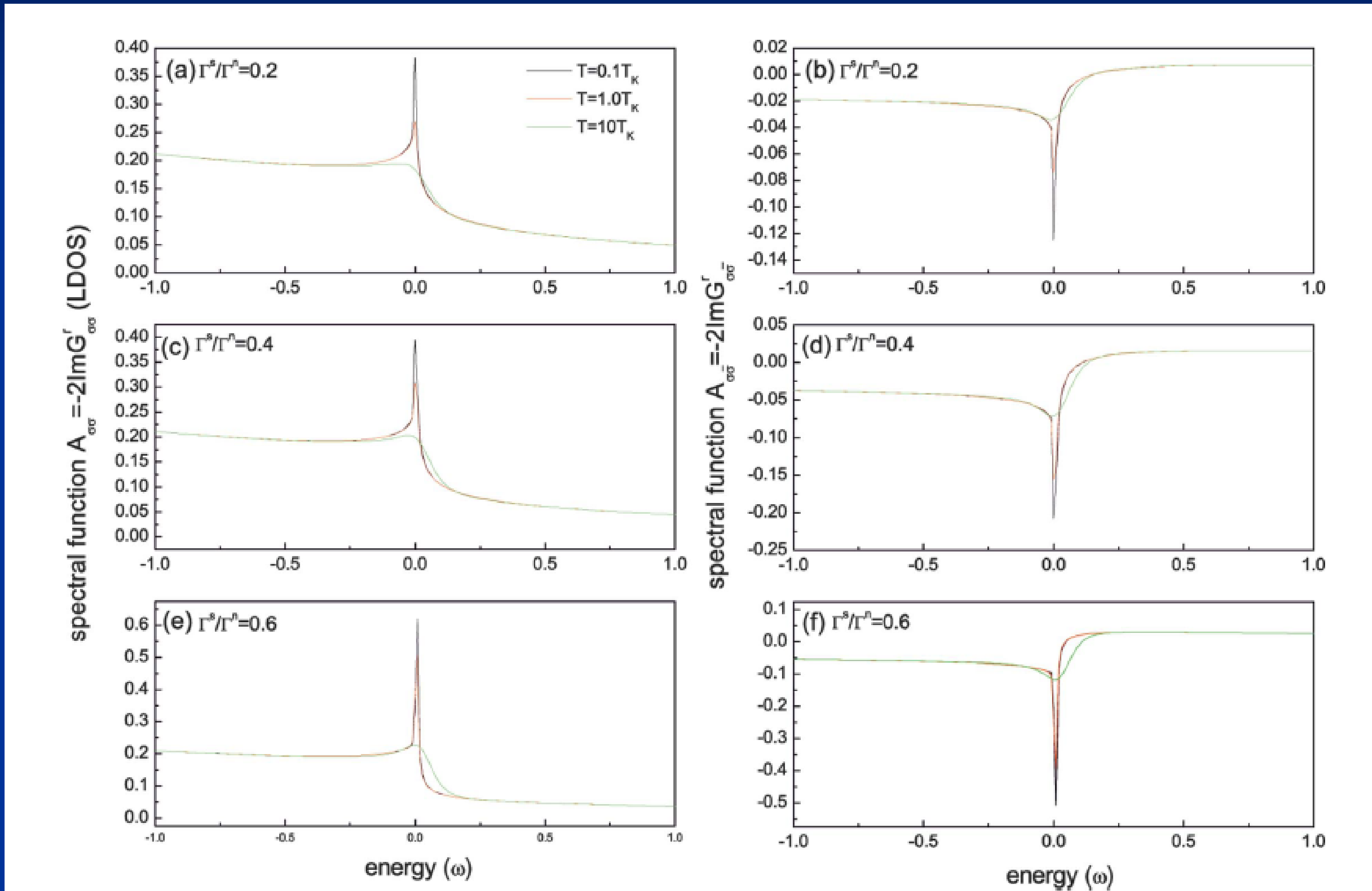

(a)
(b)
(c)
(d)
(e)
(f)
Γ*/Γ**=0.0
Γ*/Γ**=0.2
Γ*/Γ**=0.4
Γ*/Γ**=0.6
T=10T_K solid line
T=100T_K dash line
T=1.0T_K
T=0.1T_K
spectral function A_ee(ω)=-2ImG^r_ee (LDOS)
spectral function A_eS(ω)=-2ImG^r_eS
energy (ω)

DOS



(a)
(b)
(c)
(d)
(e)
(f)
Γ^a/Γ^n=0.0
Γ^a/Γ^n=0.2
Γ^a/Γ^n=0.4
Γ^a/Γ^n=0.6
T=10T_K solid line
T=100T_K dash line
T=1.0T_K
T=0.1T_K
spectral function A_σσ(ω)=-2ImG^r_σσ (LDOS)
spectral function A_σσ̄(ω)=-2ImG^r_σσ̄
energy (ω)

DOS


(a) Γs/Γn=0.2
T=0.1TK
T=1.0TK
T=10TK
(b) Γs/Γn=0.2
(c) Γs/Γn=0.4
(d) Γs/Γn=0.4
(e) Γs/Γn=0.6
(f) Γs/Γn=0.6
spectral function Aσσ=-2ImGrσσ (LDOS)
spectral function Aσσ̄=-2ImGrσσ̄
energy (ω)
energy (ω)

The canonical transformation analysis

$$H = H_{lead} + H_{DQD} + H_T$$

$$H_{lead} = \sum_{k\alpha,m} \varepsilon_{k_\alpha,\sigma} c^+_{k_\alpha,m} c_{k_\alpha,m} + h.c.$$

$$H_{DQD} = \sum_{m,\sigma} \varepsilon_m d^+_{m,\sigma_m} d_{m,\sigma_m} + U n_{m,\sigma_m} n_{m,\sigma_{\bar{m}}}$$

$$H_T = \sum_{k\alpha,m,n} V_{k_\alpha m,m} c^+_{k_\alpha,m} d_m + V_{k_\alpha m,\bar{m}} c^+_{k_\alpha,m} d_{\bar{m}} + h.c.$$

$$S = \sum_m S_m \quad ;$$

$$S_m = \left(\frac{1 - n_{\bar{m}}}{\varepsilon_m - \varepsilon_{k_\alpha}} + \frac{n_{\bar{m}}}{\varepsilon_m + U - \varepsilon_{k_\alpha}} \right) \left(c^+_{k_\alpha} d_m - h.c. \right)$$

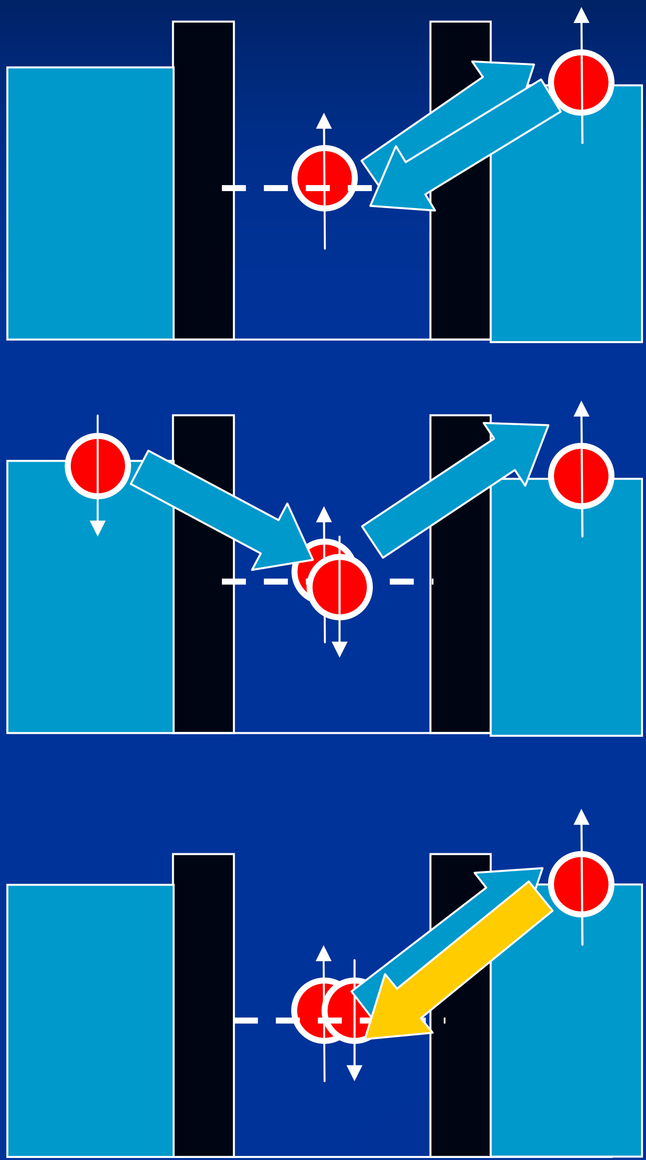
$$H = H_{lead} + H_{DQD} + H_T$$

$$H_{lead} = \sum_{k\alpha,m} \varepsilon_{k_\alpha,\sigma} c^+_{k_\alpha,m} c_{k_\alpha,m} + h.c.$$

$$H_{DQD} = \sum_{\alpha} \varepsilon_\alpha d^+_\alpha d_\alpha + U n_1 n_2$$

$$H_T = \sum_{k\alpha,m,n} V_{k_\alpha m,m} c^+_{k_\alpha,m} d_m + V_{k_\alpha m,\bar{m}} c^+_{k_\alpha,m} d_{\bar{m}} + h.c.$$

Spin flipping associated tunneling



Coherent Interdot Transition