Conductance signatures of spin correlations and quantum phase transitions in parallel quantum dots

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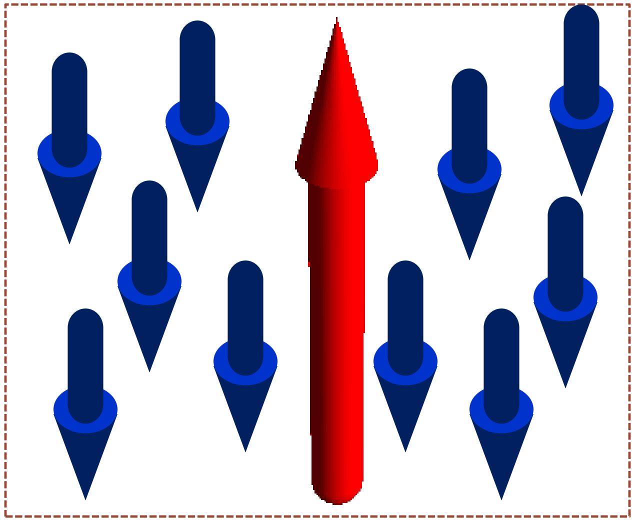
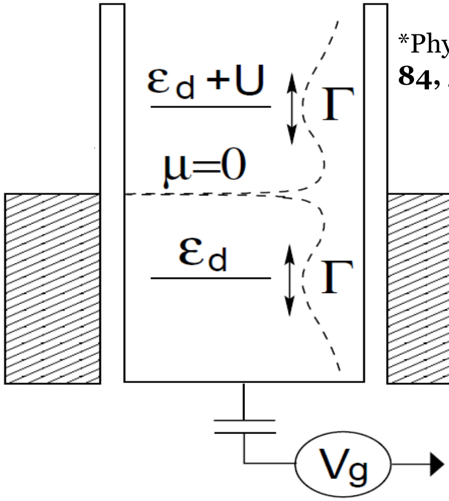
- Luis G.G.V. Dias da Silva, (Universidade de São Paulo)
- Kevin Ingersent (University of Florida)
- Nancy Sandler (Ohio University)
- Sergio Ulloa (Ohio University)

APS March Meeting, Dallas TX, March 21, 2011

Introduction (Kondo effect in Quantum dots)

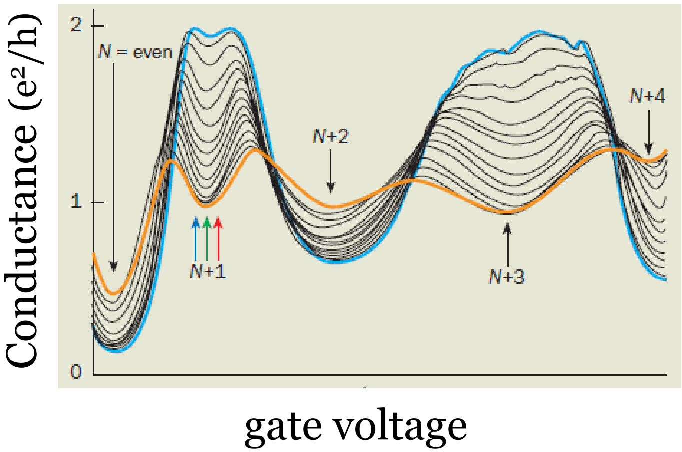
$T<T_K$





*Phys. Rev. Lett. **84, 3710 (2000).**

Phys. World **14, 33 (2001).



* Theoretical prediction in quantum dots:
- L. I. Glazman and M. E. Raikh, JETP Lett. **47**, 452 (1988)
- T. K. Ng and P. A. Lee, Phys. Rev. Lett. **61,** 1768 (1988).

•Experimental observation in quantum dots:
D. Goldhaber-Gordon et al. , Nature (London) **391,** 156 (1998).

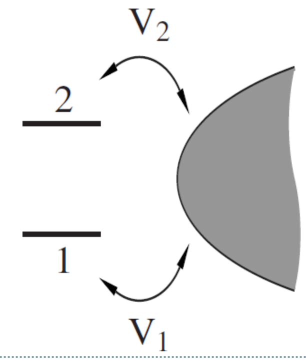
Conductance signatures of spin correlations and quantum phase transitions…

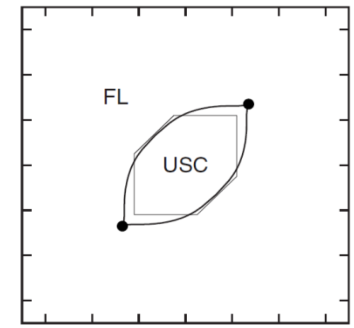
Motivation (Quantum phase transitions)

PHYSICAL REVIEW B **80**, 125117 (2009)

Correlated electron physics in two-level quantum dots: Phase transitions, transport, and experiment

David E. Logan, Christopher J. Wright, and Martin R. Galpin

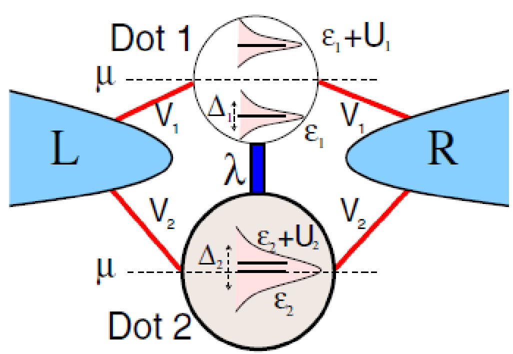


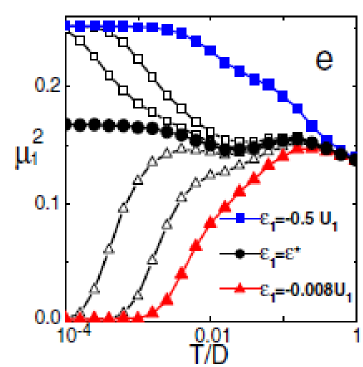


PRL **97,** 096603 (2006) PHYSICAL REVIEW LETTERS week ending 1 SEPTEMBER 2006

Zero-Field Kondo Splitting and Quantum-Critical Transition in Double Quantum Dots

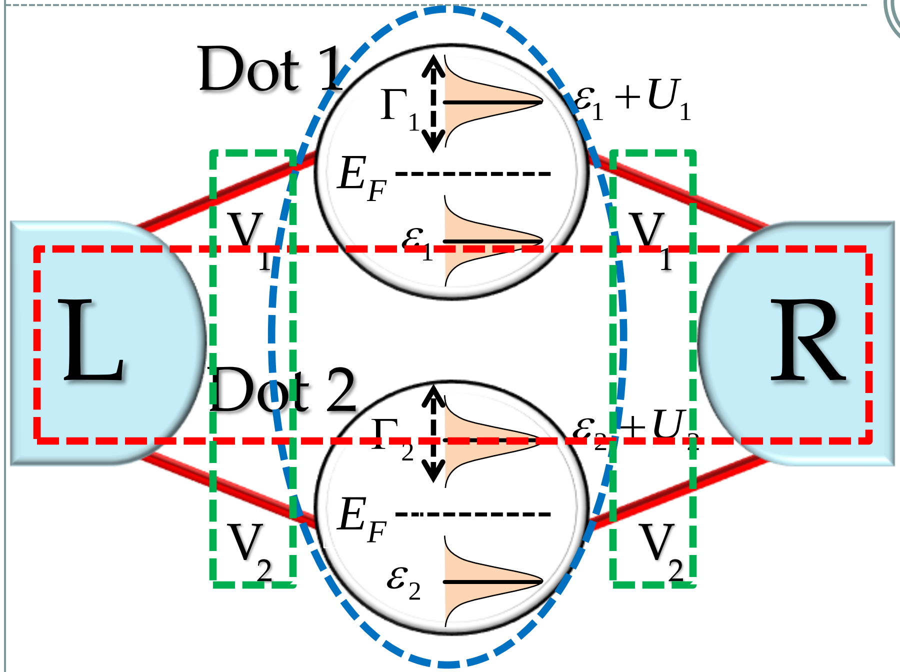
Luis G. G. V. Dias da Silva,[1,*] Nancy P. Sandler,[1] Kevin Ingersent,[2] and Sergio E. Ulloa[1]





Conductance signatures of spin correlations and quantum phase transitions…

Model



$$H_D=\sum_{i,\mu}\varepsilon_i d^\dagger_{i,\mu}d_{i,\mu}+\sum_i U_i d^\dagger_{i,\uparrow}d_{i,\uparrow}d^\dagger_{i,\downarrow}d_{i,\downarrow}$$

$$H_L=\sum_{j,\mathbf{k},\mu}\varepsilon_{j,\mathbf{k}}c^\dagger_{j,\mathbf{k},\mu}c_{j,\mathbf{k},\mu}$$

$$H_{D-L}=\sum_{i,j,\mathbf{k},\mu}V_i\left(d^\dagger_{i,\mu}c_{j,\mathbf{k},\mu}+c^\dagger_{j,\mathbf{k},\mu}d_{i,\mu}\right)$$

$$H=\underline{H_D}+H_L+H_{D-L}$$

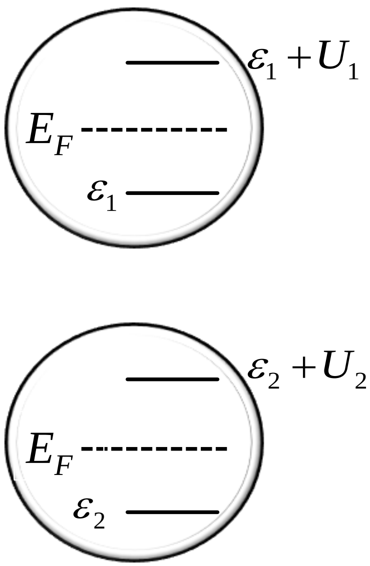
-Constant density of states $\qquad \rho=\frac{1}{2D}$

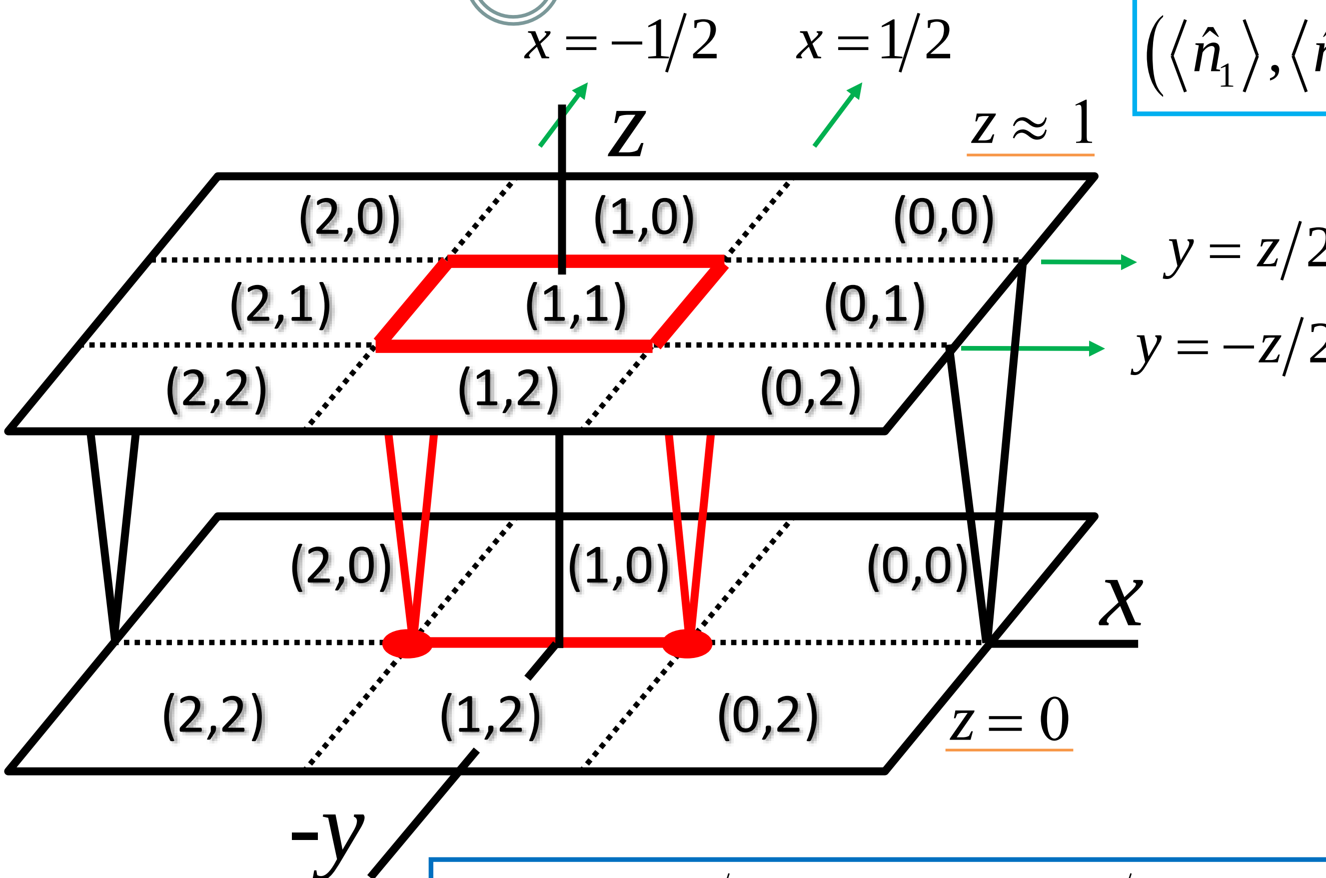
-Constant hybridization strength $\qquad \Gamma_i=\pi\rho V_i^2$

<u>Studied by Numerical Renormalization Group</u>

half bandwidth D~ a few eV

Ground states of the isolated dots





$$\left(\langle \hat{n}_1 \rangle, \langle \hat{n}_2 \rangle\right)$$

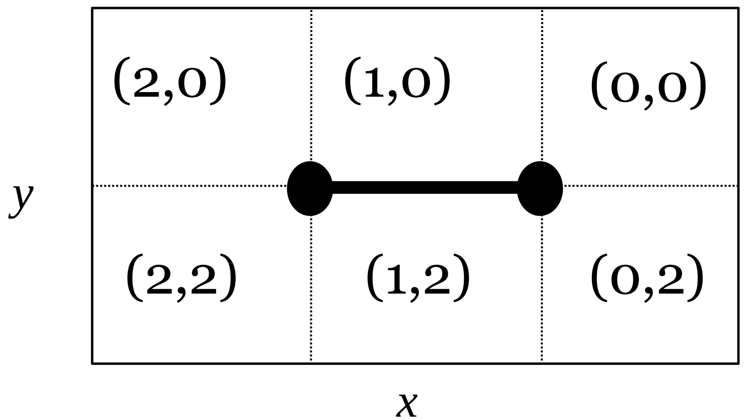
-Strong-Coupling phase

-Free-Moment phase

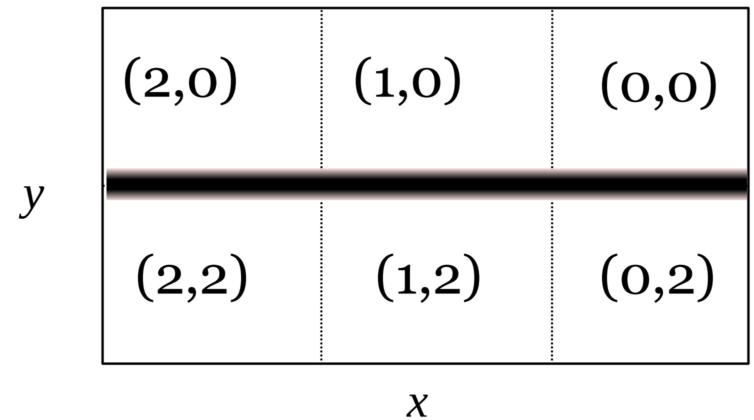
$$x = \frac{\varepsilon_1 + U_1/2}{U_1} \qquad y = \frac{\varepsilon_2 + U_2/2}{U_1} \qquad z = \frac{U_2}{U_1}$$

Regimes analyzed in the present work

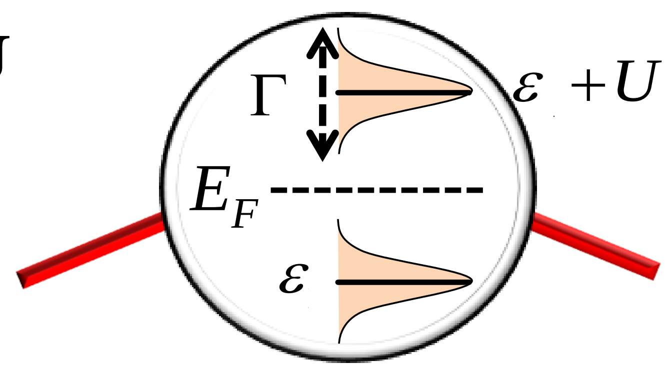
$z = 0$ ($U_2 = 0$)



$z \ll 1$ ($U_2 \ll U_1$)

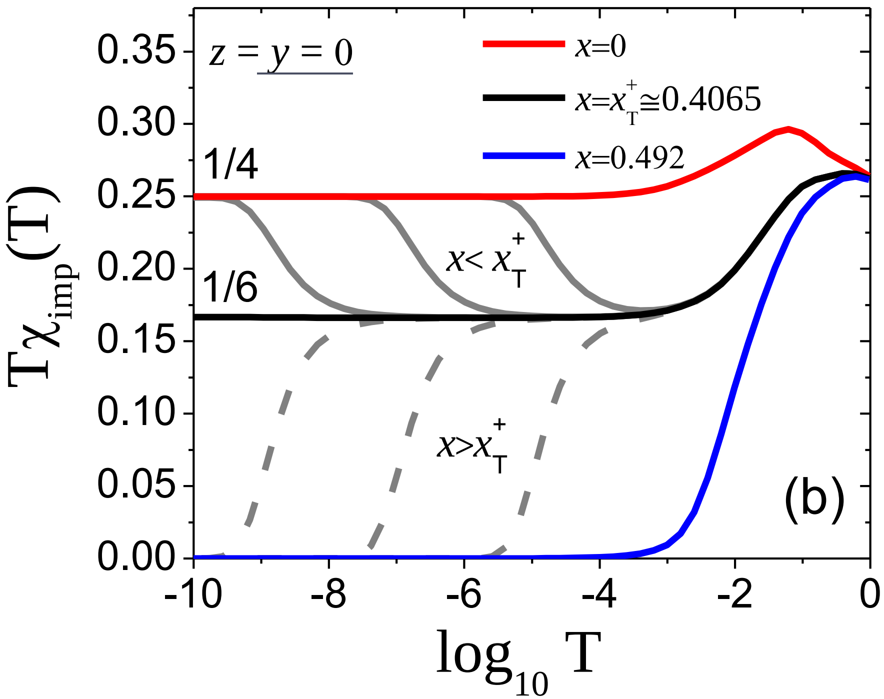


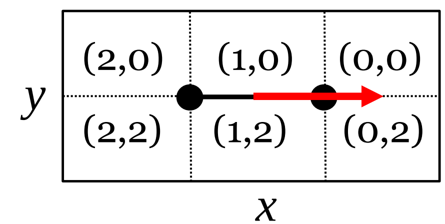
- Kondo regime is reached when $\Gamma \ll U$
- In our work, dot 2 <u>never</u> reaches the Kondo regime.

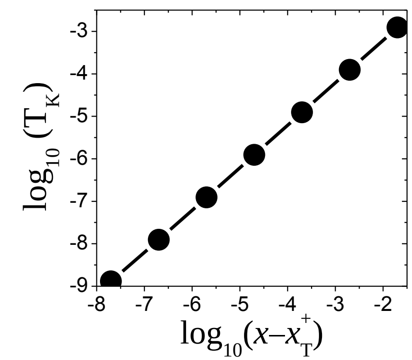


Non-interacting dot-2, z = 0 ($U_2 = 0$)

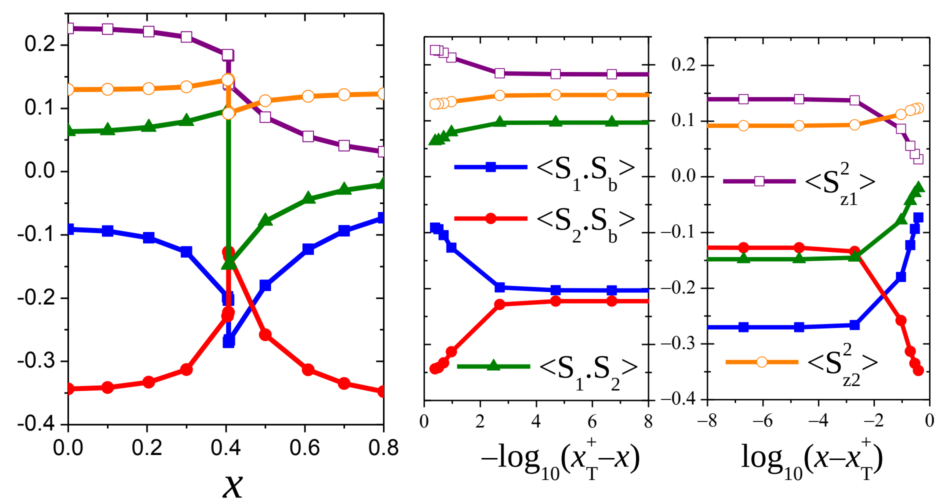
First-order level-crossing transition



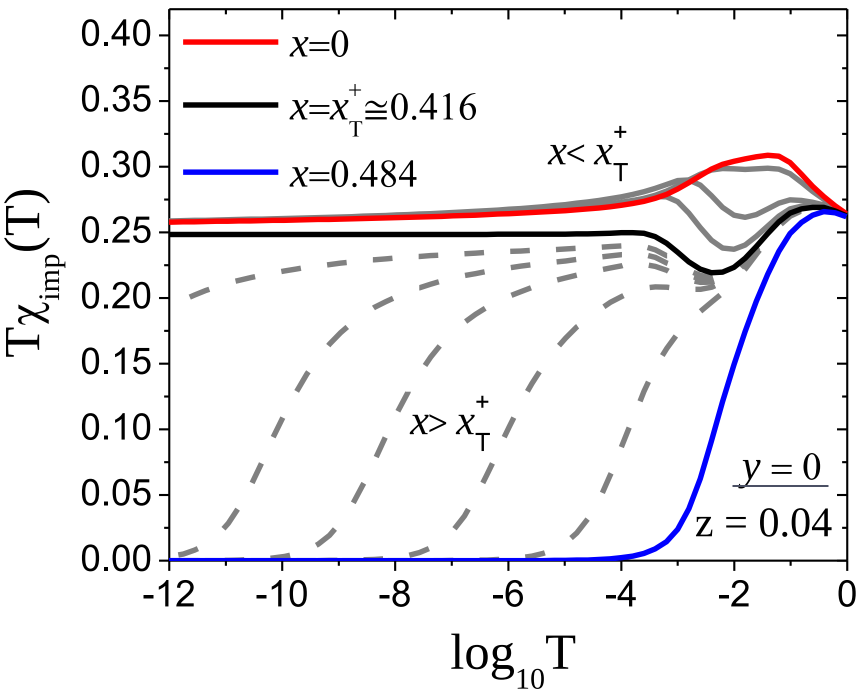




$$x = \frac{\varepsilon_1 + U_1/2}{U_1} \qquad y = \frac{\varepsilon_2 + U_2/2}{U_1} \qquad z = \frac{U_2}{U_1}$$

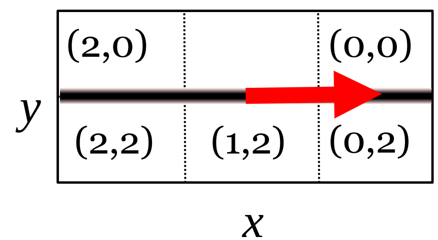


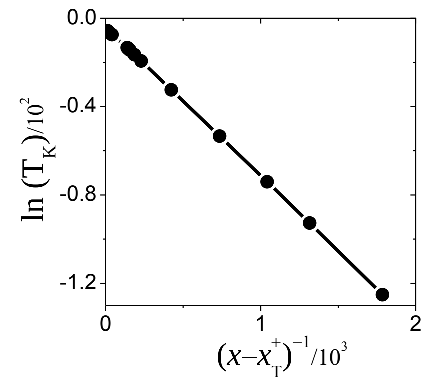
Interacting dot-2, $0 < z\ (= 0.04) \ll 1$ $(U_2 \ll U_1)$

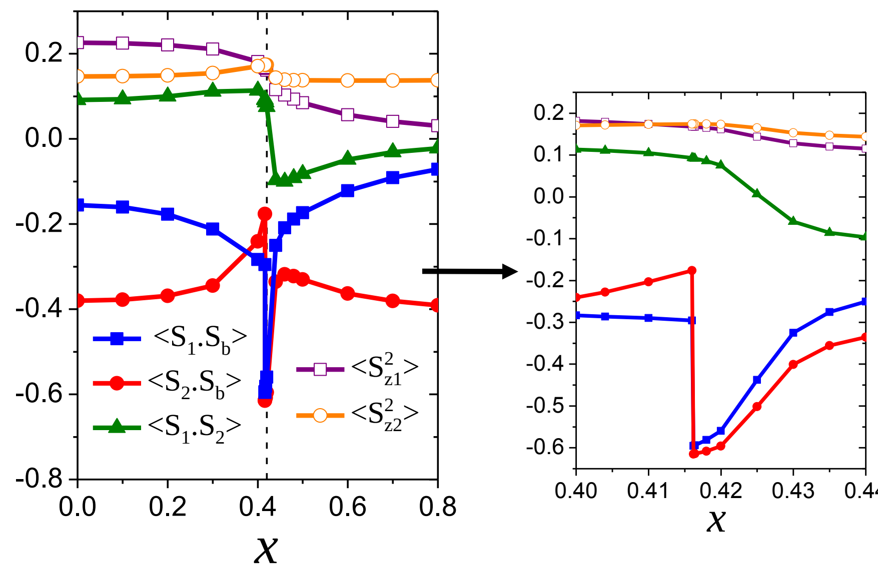


$$x = \frac{\varepsilon_1 + U_1/2}{U_1} \qquad y = \frac{\varepsilon_2 + U_2/2}{U_1} \qquad z = \frac{U_2}{U_1}$$

Kosterlitz-Thouless like transition







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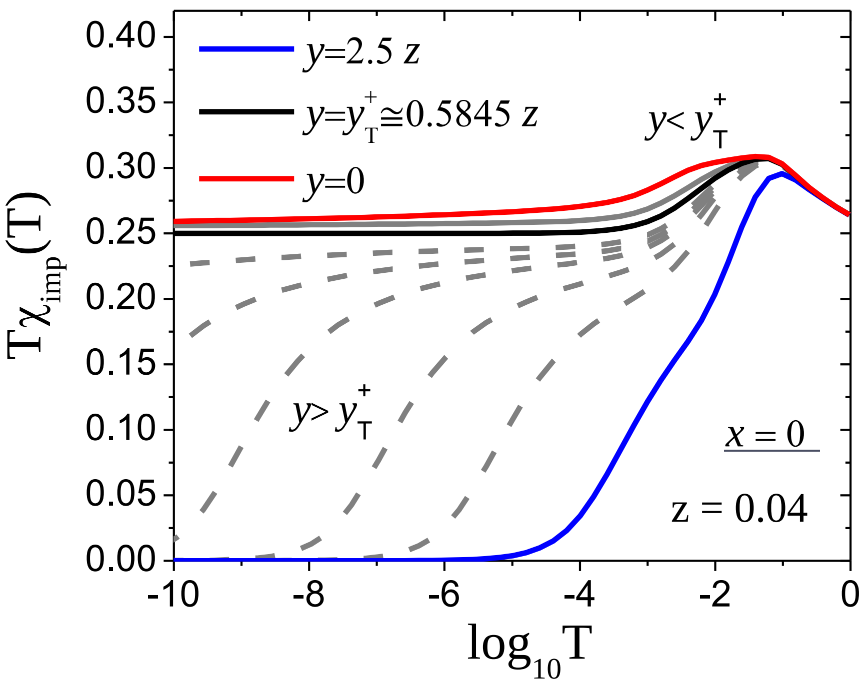

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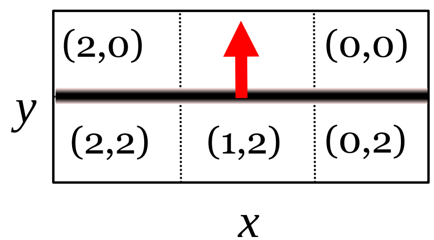
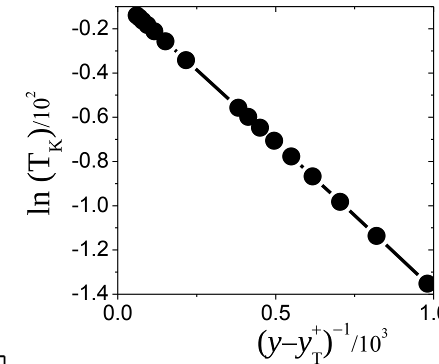
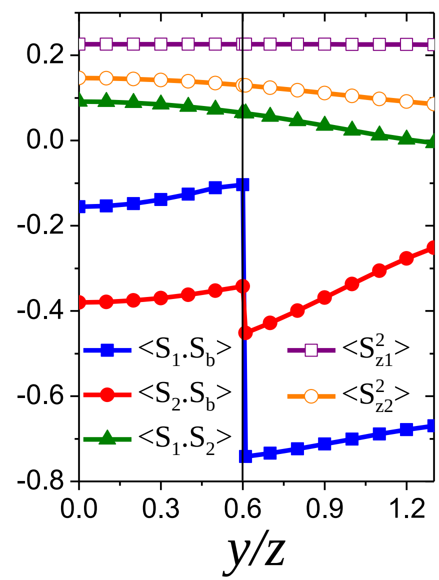
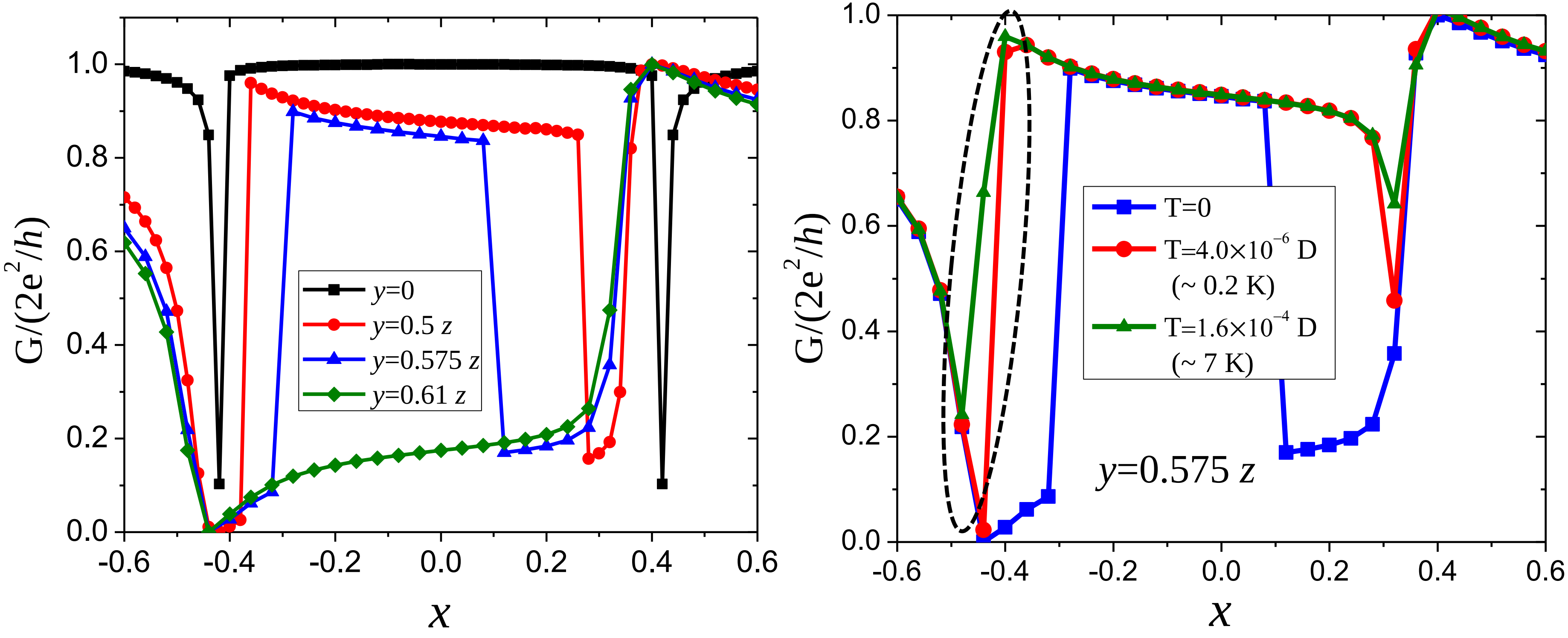






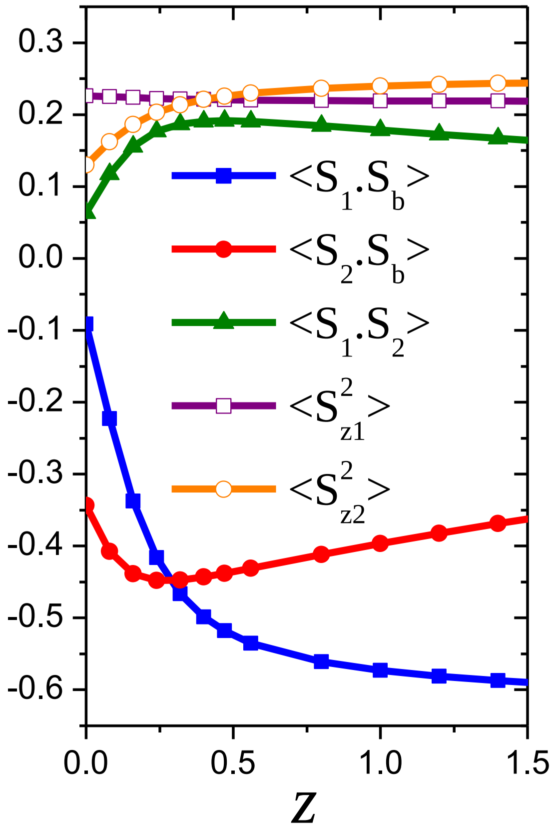
Linear conductance

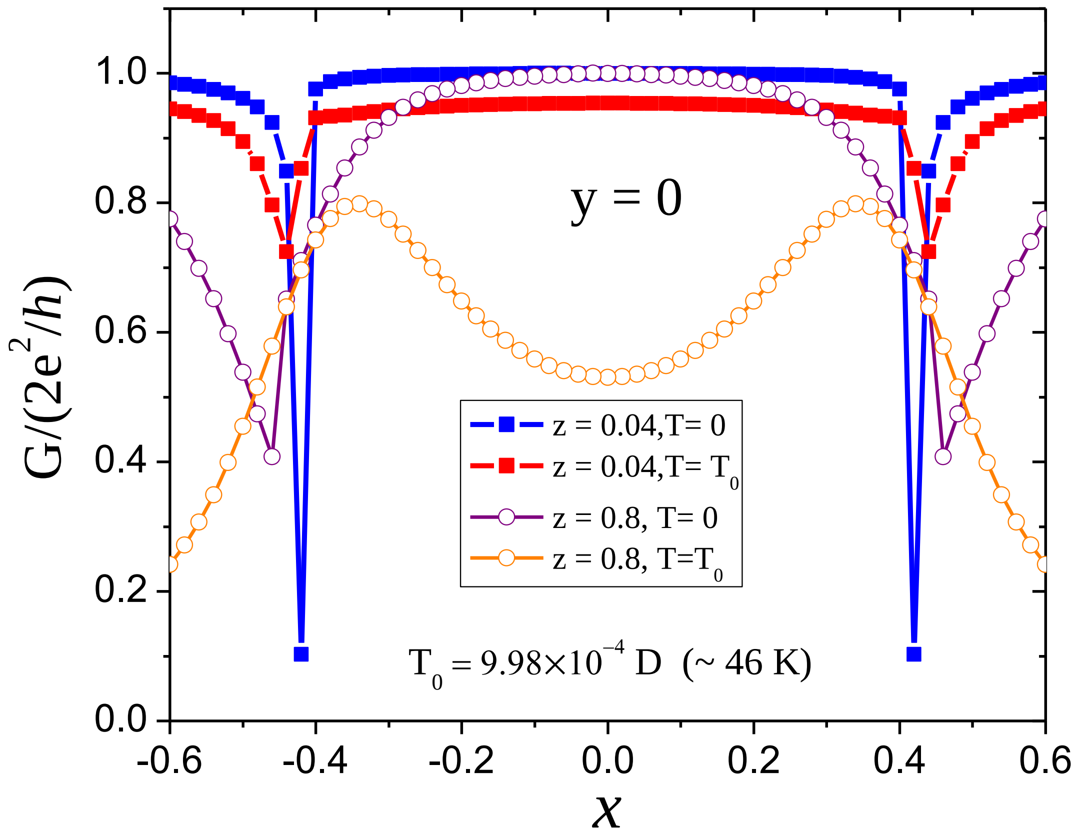
$$y_T^+ = 0.5845\,z$$



$$x = \frac{\varepsilon_1 + U_1/2}{U_1} \quad y = \frac{\varepsilon_2 + U_2/2}{U_1} \quad z = \frac{U_2}{U_1}$$

Local-moment vs. Under-screened spin-1





$$x = \frac{\varepsilon_1 + U_1/2}{U_1} \qquad y = \frac{\varepsilon_2 + U_2/2}{U_1} \qquad z = \frac{U_2}{U_1}$$

Summary

1. We have studied a parallel double quantum dot system connected to a single channel, and in which dot-1 is in Kondo regime while dot-2 is not.

2. The system exhibits a quantum phase transition separating Strong-Coupling and Free-Moment phases.

3. For $U_2=\varepsilon_2=0$, there is a first-order level-crossing quantum phase transition, as a function of ε_1. For $0<U_2\ll U_1$ the transition has a Kosterlitz-Thouless nature.

4. Within the Free-Moment phase, for $0\leq U_2\ll U_1$, the residual two-fold degree of freedom is localized in dot 1, as shown by the spin correlations. For larger U_2, that degree of freedom resides in a Kondo (under)screening cloud that is delocalized over both dots and extends into the leads.

5. The conductance exhibits particular features depending on the quantum phase of the system.

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