Seeing the strongly-correlated zero-bias anomaly in double quantum dot measurements

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NSERC CRSNG
bulk strongly-correlated materials

double quantum dots

Connecting
Transition metal oxides

What does disorder do to strongly correlated systems?

What do interactions do to disordered systems?
Zero-bias anomalies

- **Altshuler-Aronov**
  - Weak interactions & disorder

- **Efros-Shklovskii**
  - Atomic limit, $1/r$ Coulomb

*Butko, et al., PRL 2000*
Zero-bias anomalies

Altshuler-Aronov weak interactions & disorder
Butko, et al, PRL 2000

Efros-Shklovskii atomic limit, 1/r Coulomb

strongly-correlated expt
Zero-bias anomalies

Altshuler-Aronov
weak interactions & disorder

Butko, et al, PRL 2000

Efros-Shklovskii
atomic limit, 1/r Coulomb

Strongly-correlated expt


Strongly-correlated theory

Chiesa, et al, PRL 2008
strongly correlated systems: kinetic-energy-driven zero bias anomaly

\[ \mathcal{H} = -t \sum_{\langle i,j \rangle, \sigma} c_{i\sigma}^\dagger c_{j \sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + \sum_{i, \sigma} \epsilon_i n_{i\sigma} \]

ZBA independent of interaction strength disorder strength chemical potential width linear in \( t \)

Chiesa, et al, PRL 2008
strongly correlated systems: kinetic-energy-driven zero bias anomaly

\[ \mathcal{H} = -t \sum_{\langle i,j \rangle, \sigma} c^\dagger_{i\sigma} c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + \sum_{i, \sigma} \epsilon_i n_{i\sigma} \]

ZBA independent of interaction strength, disorder strength, chemical potential width linear in \( t \)

ensemble of two-site systems
\( \rightarrow \) ZBA with the same parameter dependence as the bulk crystal

Wortis & Atkinson, PRB 2010

Chiesa, et al, PRL 2008
parallel-coupled double quantum dots

\[
\mathcal{H} = -t \sum_{\langle ij \rangle, \sigma} c_{i\sigma}^\dagger c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + \sum_{i, \sigma} \epsilon_i n_{i\sigma}
\]

Wang, et al, APL 2011
lower drain barrier -> focus on transitions which add one particle to the ground state

Wang, et al, APL 2011
stability diagrams

drain
source

eV_1

eV_2

(0,0) (1,0) (2,0) (0,1) (1,1) (2,1) (0,2) (1,2) (2,2)
stability diagrams

Chan, et al., APL 2002
stability diagrams

Chan, et al, APL 2002
including nearest-neighbor interactions

\[ \mathcal{H} = -t \sum_{\langle ij \rangle, \sigma} c_{i\sigma}^\dagger c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + \sum_{i, \sigma} \epsilon_i n_{i\sigma} + V \sum_{\langle ij \rangle} n_{i} n_{j} \]
seeing the zero bias anomaly in stability diagrams

lower barrier (increase hopping)
seeing the zero bias anomaly in stability diagrams

lower barrier (increase hopping)

shows suppression of density of states at zero bias
BUT does not distinguish between different mechanisms
seeing the energy dependence of the zero bias anomaly

$U=1$

$t=0.6$

$V_{bias} = 0.2$
seeing the energy dependence of the zero bias anomaly

U=1
no zero-bias anomaly
little $V_{\text{bias}}$ dependence

t=0.6
$V_{\text{bias}}$ 0.2 0.4 0.6
seeing the energy dependence of the zero bias anomaly

$U=8$

$t=0$

$t=0.6$

$V_{\text{bias}}$
seeing the energy dependence of the zero bias anomaly

$U=8$

zero-bias anomaly

strong $V_{\text{bias}}$ dependence

$t=0$

$t=0.6$

$V_{\text{bias}}$
Summary

Connecting and

Using DQDs to see the physics of the zero-bias anomaly in bulk disordered strongly-correlated materials

- simple: less ensemble-averaged current at zero bias when the tunnel barrier is lowered
- better: use differential conductance as a function of $V_{bias}$ to distinguish the kinetic-energy-driven effect, a unique signature of strong correlations