Interference spin-blockade in symmetric nanojunctions

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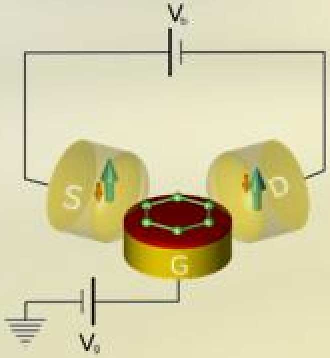
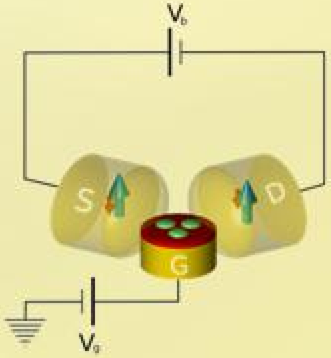


Quantum Dot ISET

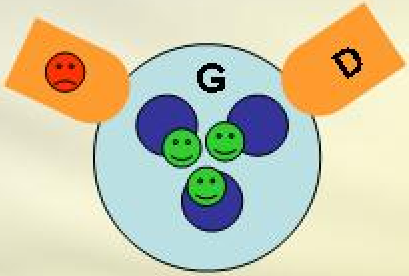
Molecular ISET



Interference SET...

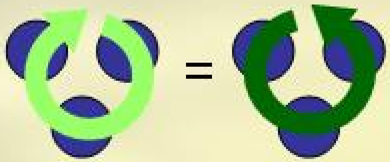
- **Weak coupling**
- **Coulomb** interaction
- Nanometer **scale**
- **Low** temperature

⇨ Coulomb blockade



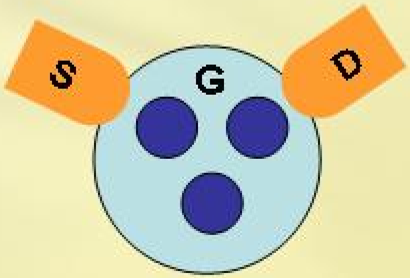
$$\hbar\Gamma \ll k_{\mathrm{B}}T \ll \Delta E_{\mathrm{ex}}$$

- **Rotational** symmetry ⇨ Orbitally degenerate states



$$E_1 = E_2$$

- Contact **geometry** ⇨ Contact symmetry breaking

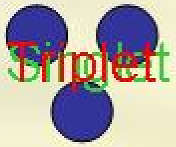


$$\frac{\gamma_{1L}}{\gamma_{2L}} \neq \frac{\gamma_{1R}}{\gamma_{2R}}$$

... with a magnetic flavour

- **Coulomb** interaction
- Nanometer **scale**

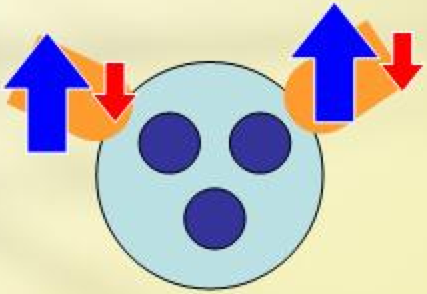
⇨ **Exchange splitting**



$$E_{\text{triplet}} \neq E_{\text{singlet}}$$

- Parallel **ferromagnetic** leads

⇨ **Spin symmetry breaking**



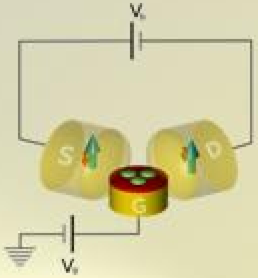
$$\Gamma_{\alpha\uparrow} \neq \Gamma_{\alpha\downarrow}$$

The interplay between orbital and spin degree of freedom

⇩

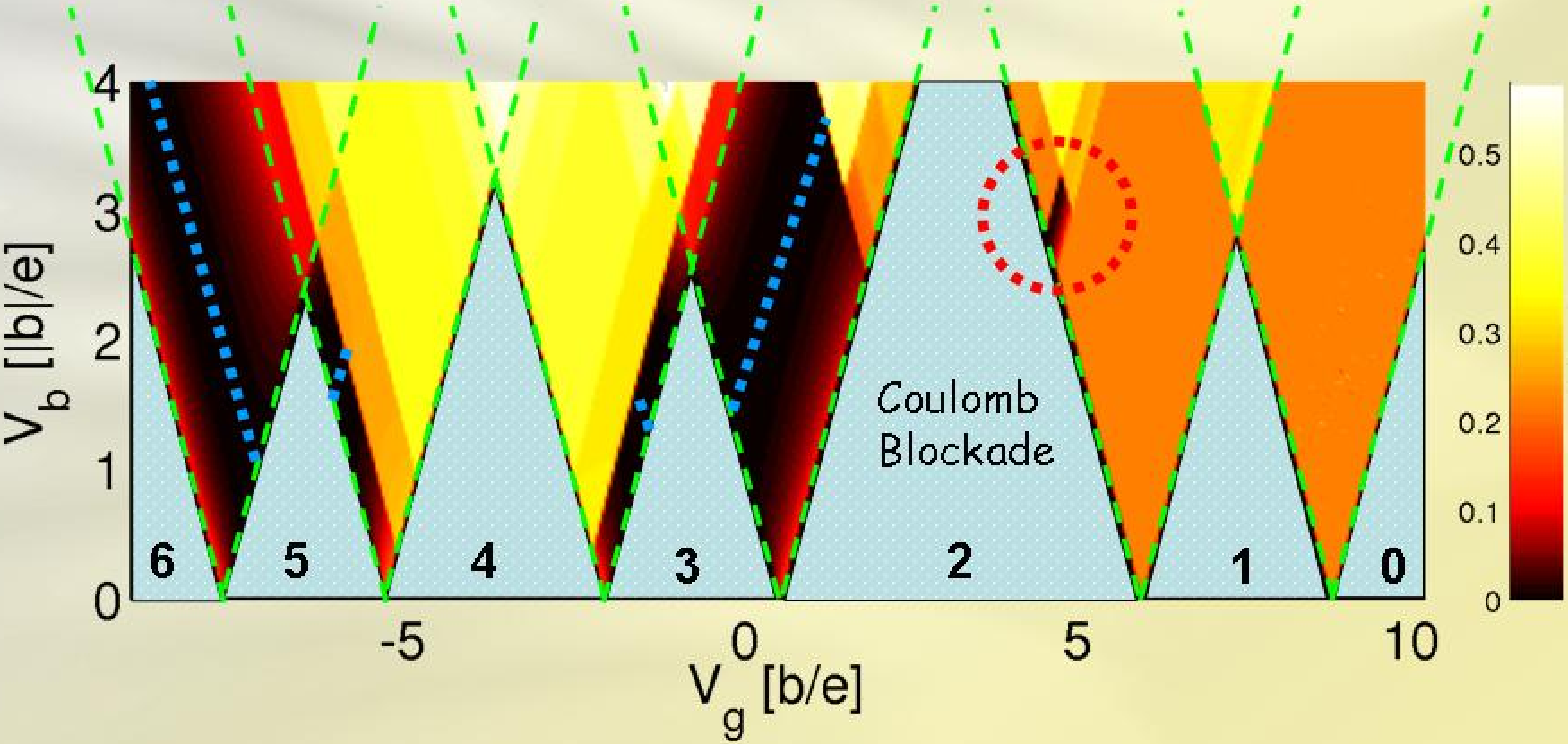
excited state blocking and all-electrical spin control on the system.

Current blocking

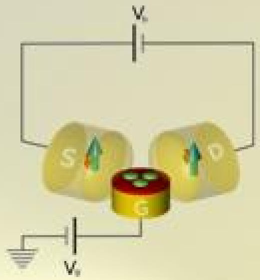


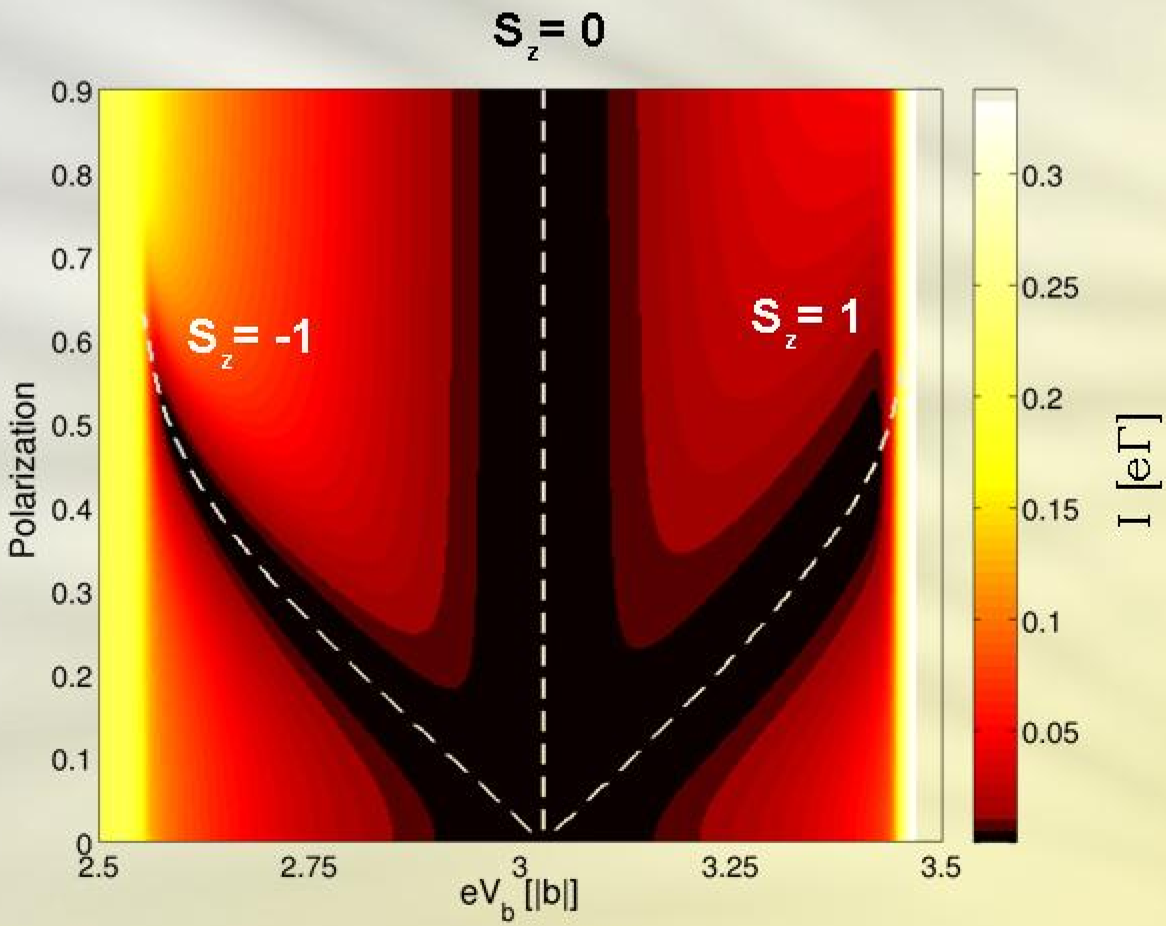
Interference Blockade
--ground states--

Interference Blockade
--excited state--



Polarized leads





Parallel polarized leads

No magnetic field on the system

All-electric spin control

The Hamiltonian

$$H = H_{\text{sys}} + H_{\text{leads}} + H_{\text{tun}}$$

$$\begin{aligned} H_{\text{sys}} = \xi_0 \sum_{i\sigma} d^\dagger_{i\sigma} d_{i\sigma} + b \sum_{i\sigma} \left(d^\dagger_{i\sigma} d_{i+1\sigma} + d^\dagger_{i+1\sigma} d_{i\sigma} \right) \\ +U \sum_i \left(n_{i\uparrow} - \tfrac{1}{2}\right)\left(n_{i\downarrow} - \tfrac{1}{2}\right) \\ +V \sum_i \left(n_{i\uparrow} + n_{i\downarrow} - 1\right)\left(n_{i+1\uparrow} + n_{i+1\downarrow} - 1\right) \end{aligned}$$

Extended Hubbard Hamiltonian with on-site and nearest neighbors **Coulomb interaction**

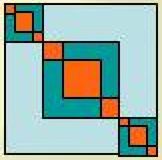
$$H_{\text{tun}} = t \sum_{\alpha k \sigma} (c^\dagger_{\alpha k \sigma} d_{\alpha\sigma} + d^\dagger_{\alpha\sigma} c_{\alpha k \sigma}) \longleftarrow$$

Tunnelling restricted to the dot closest to the corresponding lead

H_{leads} Ferromagnetic leads with equal parallel polarization

Generalized Master Equation

- We start with the **Liouville** equation: $\dot{\rho} = -\frac{i}{\hbar}[\mathcal{H}, \rho]$



- We consider a reduced density matrix block-diagonal in spin, energy and particle number. We keep coherencies between orbitally degenerate states.

- The **Generalized Master Equation** is an equation of motion for the reduced density matrix. We calculate it in the lowest non-vanishing order in the coupling to the leads and in the Markov approximation. It reads:

$$\dot{\sigma} = \underbrace{-\frac{i}{\hbar}[H_{\mathrm{sys}}, \sigma]}_{\text{Coherent dynamics}} \underbrace{- \frac{i}{\hbar}[H_{\mathrm{eff}}, \sigma]}_{\text{Effective internal dynamics}} + \underbrace{\mathcal{L}_{\mathrm{tun}}\sigma}_{\text{Tunnelling dynamics}}$$

Coherent dynamics

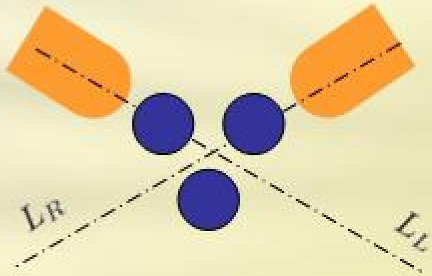
Effective **internal** dynamics

Tunnelling dynamics

The effective Hamiltonian

The effective Hamiltonian is expressed in terms of **angular momentum** operators and **renormalization frequencies**:

$$H_{\text{eff}} = \sum_{\alpha S_z} \omega_{\alpha S_z} L_\alpha ,$$



In particular in the Hilbert space of the 2 particle first excited states

$$L_\alpha = \frac{\hbar}{2} \begin{pmatrix} 1 & e^{i2|\ell|\phi_\alpha} \\ e^{-i2|\ell|\phi_\alpha} & 1 \end{pmatrix}$$

$$\omega_{\alpha S_z} = \frac{1}{\pi} \sum_{\sigma'\{E\}} \Gamma^0_{\alpha\sigma'} \Big[\langle 2_1 \ell S_z | d_{M\sigma'} | 3\{E\} \rangle \langle 3\{E\} | d^\dagger_{M\sigma'} | 2_1 \; -\ell\, S_z \rangle p_\alpha(E - E_{2_1}) + \langle 2_1 \ell S_z | d^\dagger_{M\sigma'} | 1\{E\} \rangle \langle 1\{E\} | d_{M\sigma'} | 2_1 \; -\ell\, S_z \rangle p_\alpha(E_{2_1} - E) \Big]$$

Bias and gate dependent

Blocking conditions

The interference blocking state:

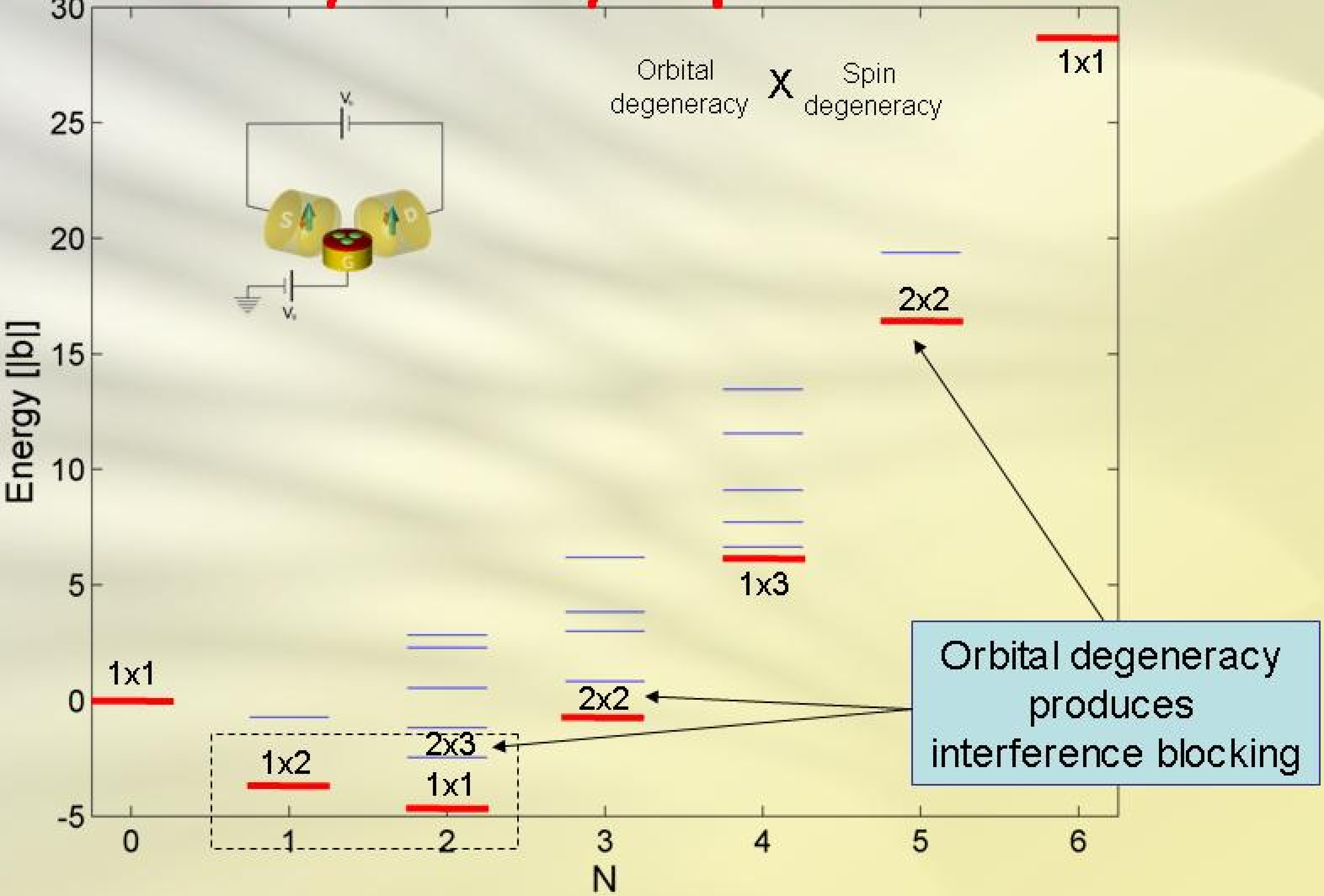
- is a linear combination of degenerate system eigenstates
- is achievable from the global minimum via a finite number of allowed transitions
- has vanishing tunnelling amplitudes for all energetically allowed outgoing transitions

$$\mathcal{L}_{\mathrm{tun}}\sigma_{\mathrm{B}} = 0$$

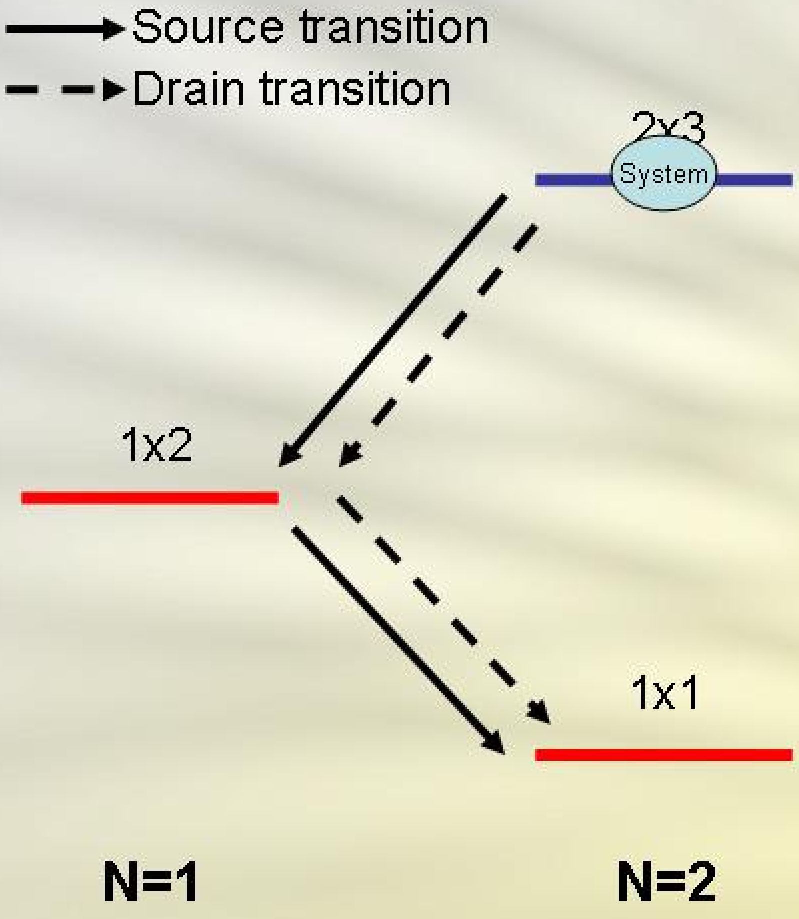
- is an eigenstate of the effective Hamiltonian

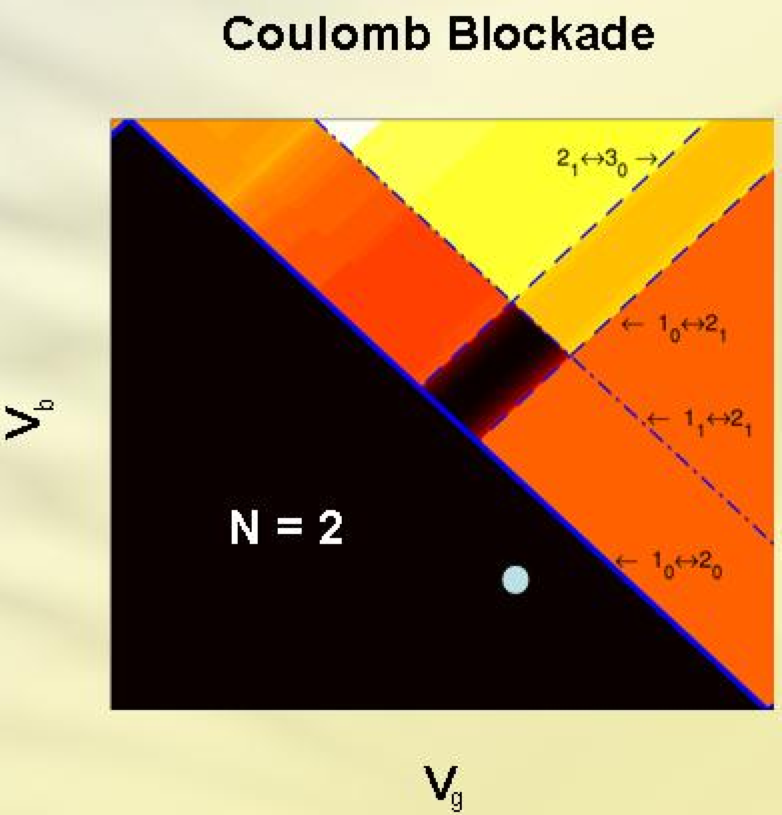
$$[H_{\mathrm{eff}}, \sigma_{\mathrm{B}}] = 0$$

Many-body spectrum

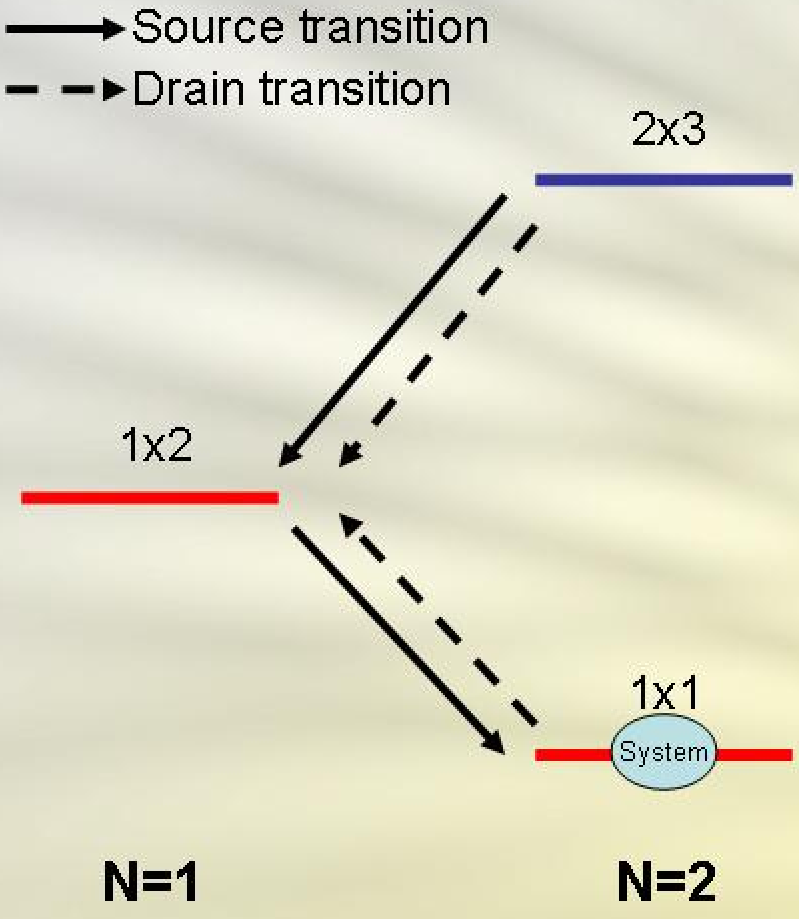


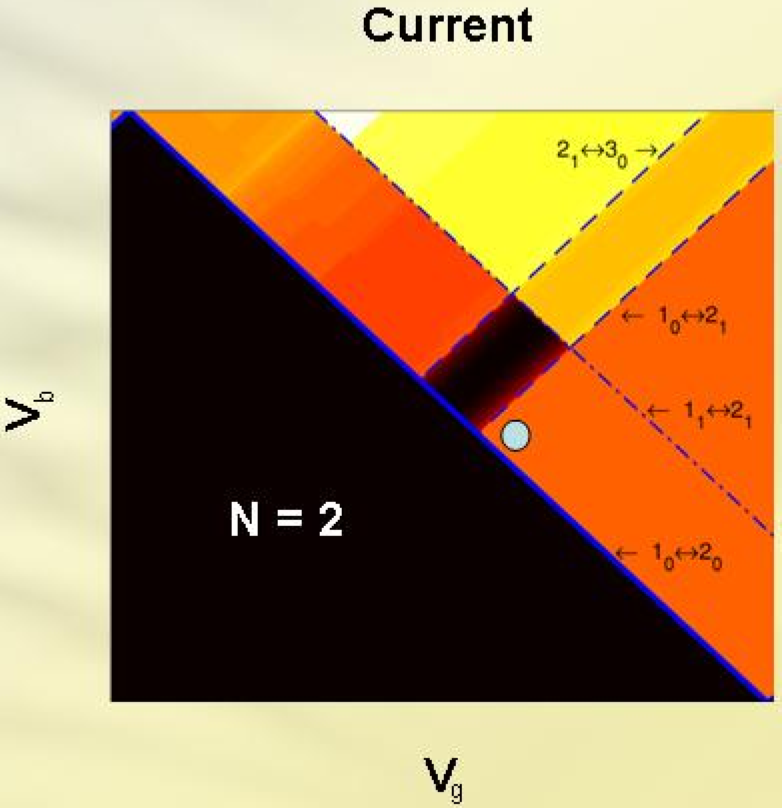
Excited state blocking



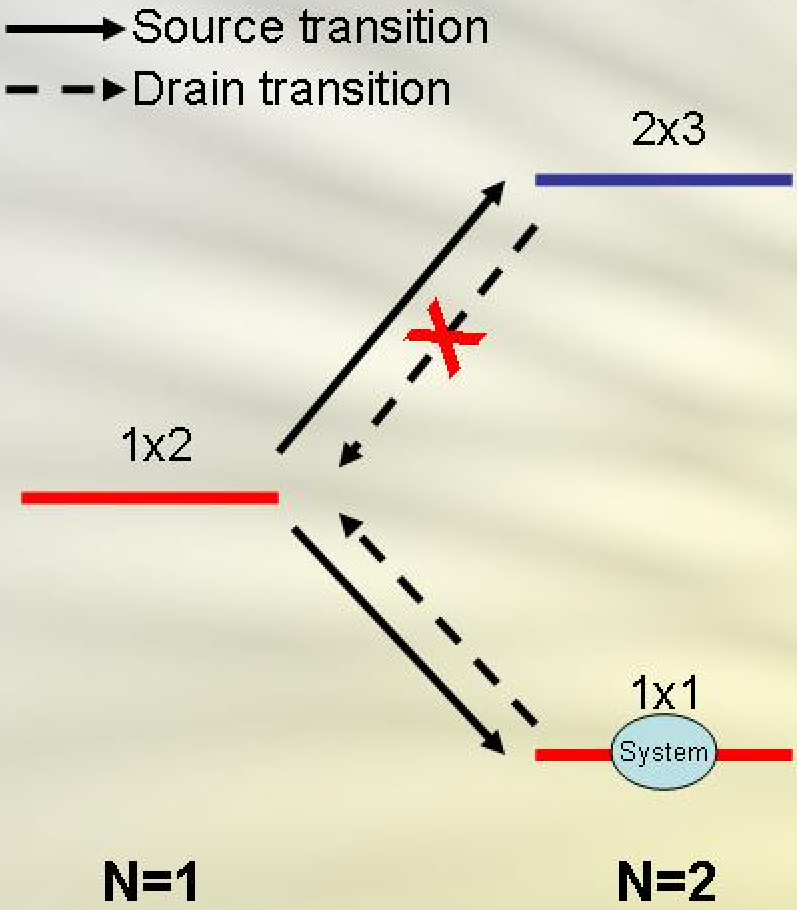


Excited state blocking

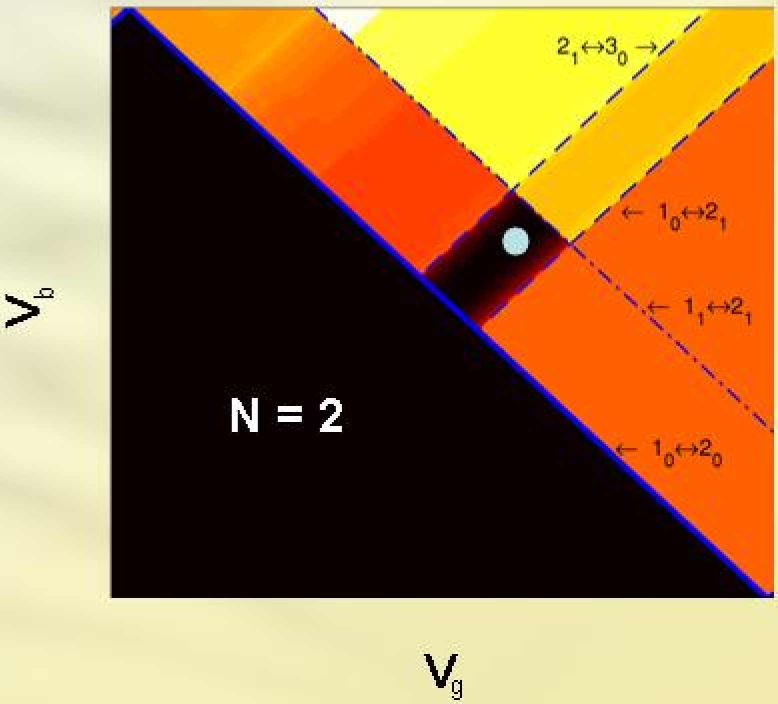




Excited state blocking



Interference Blockade

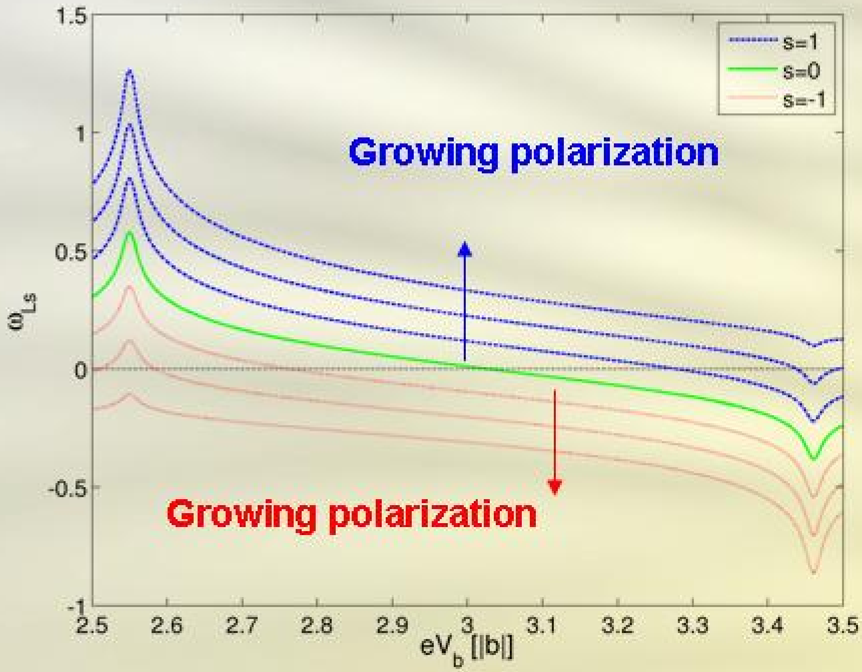


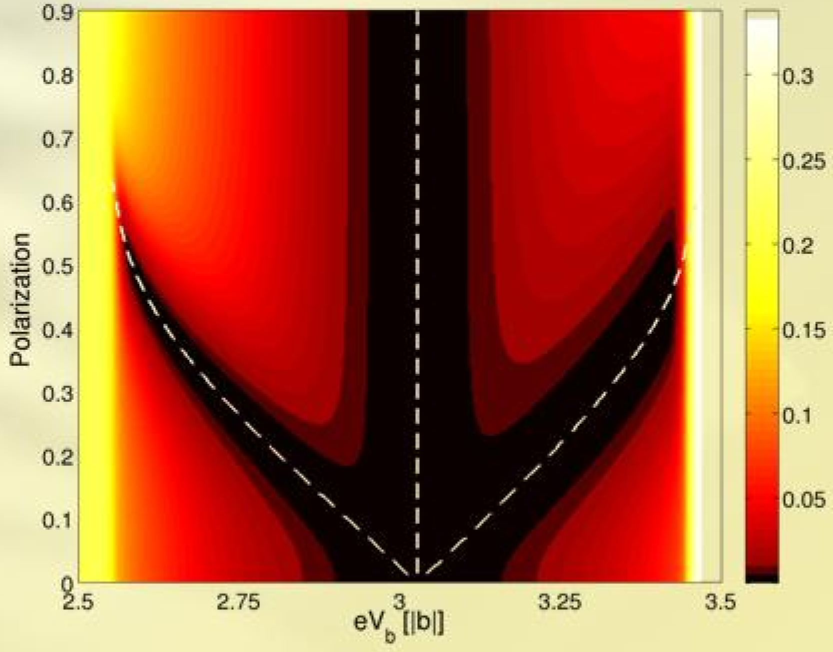
Three linear combinations of 2-particle excited states are coupled **ONLY to the source.**

Triplet splitting

The states decoupled from the right lead are eigenstates of L_R. They are eigenstates of H_{eff} only if

$$\omega_{L\,S_z} = 0$$





Conclusions

- Symmetric nanojunctions have an **orbitally degenerate manybody spectrum**

- Destructive interference between orbitally degenerate states leads to the formation of ground- as well as **excited- interference blocking states**

- Exploiting the interplay of interference blocking and Coulomb interaction we could achieve **all-electrical spin control of a triple dot junction**

References:

G. Begemann, D. Darau, **AD**, and M. Grifoni *PRB* **77**, 201406(R) (2008)

D. Darau, G. Begemann, **AD**, and M. Grifoni *PRB* **79**, 235404 (2009)

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