Harnessing a Quantum Dynamical Phase Transition in Experimental Systems.

Horacio M. Pastawski

Universidad Nacional de Córdoba

Facultad de Matemática, Astronomía y Física

Instituto de Física Enrique Gaviola

IFEG
CONICET
UNC

The Abdus Salam
International Centre for Theoretical Physics

Autumn College on Non-Equilibrium Quantum Systems
2 - 13 May 2011
Buenos Aires, Argentina

held at University of Buenos Aires, Dept. of Physics, Mathematics and Computer Science
Aula Magna of Pabellon I

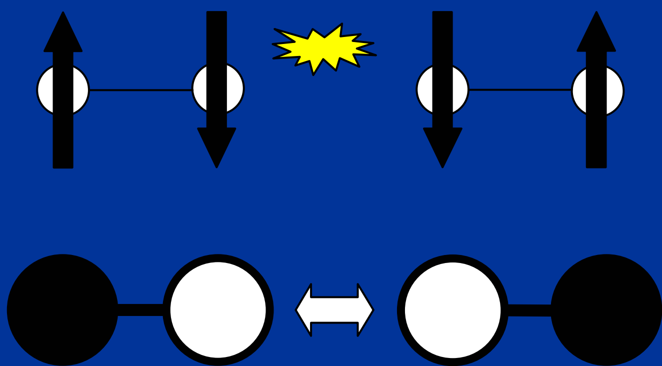
co-sponsored by:
Alexander-von-Humboldt Foundation, Bonn
Universidad de Buenos Aires (UBA)
Institute for Complex Adaptive Matter (ICAM), Davis

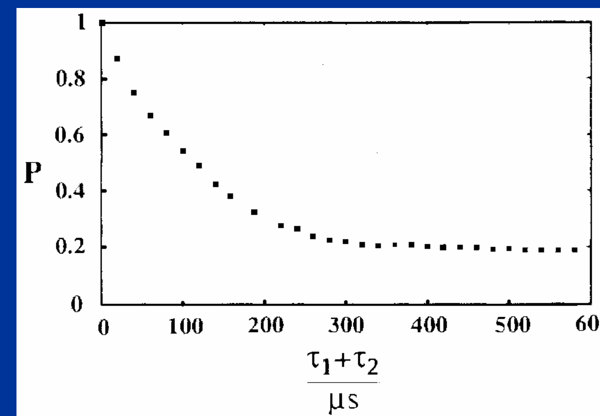

Córdoba 1613
Buenos Aires
Bariloche
MARE DEL NORT
MARE DEL SUD
AMERICA MERIDIONALE
Auttore
Il P. M. Coronelli M. C. Cosmografo
della SERENISSIMA REPUB. DI VENETIA
Dedicata
ALL'ILL. et ECC. SIG. IL SIGN.
PIETRO FOSCARINI

Wigner-Jordan: spins → fermions

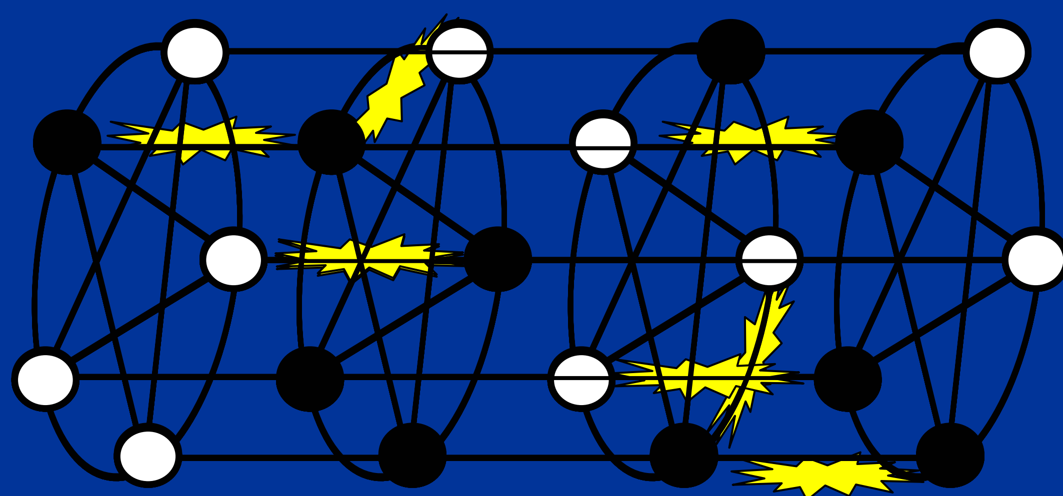
flip-flop XY →hopping of electrons

Ising → Hubbard





Zhang, Meier y Ernst *Phys.Rev.Lett.*1992



interactions

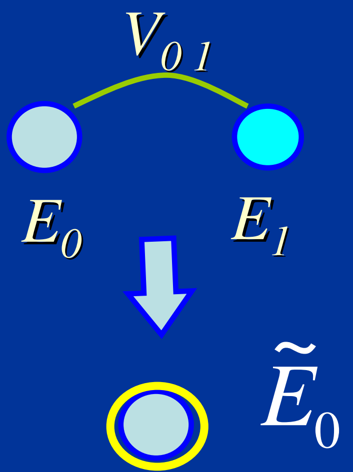
ON / OFF

and scaled

with r.f. pulses

complex many-body interactions→ spin “diffusion”

Effective Hamiltonian for CLOSED Systems



$$\begin{pmatrix} E_0 & V_{0,1} \\ V_{1,0} & E_1 \end{pmatrix}\begin{pmatrix} u_0 \\ u_1 \end{pmatrix} = \varepsilon \begin{pmatrix} u_0 \\ u_1 \end{pmatrix}$$

$$u_1 = V_{1,0}\,\frac{1}{\varepsilon - E_0}\,u_0$$

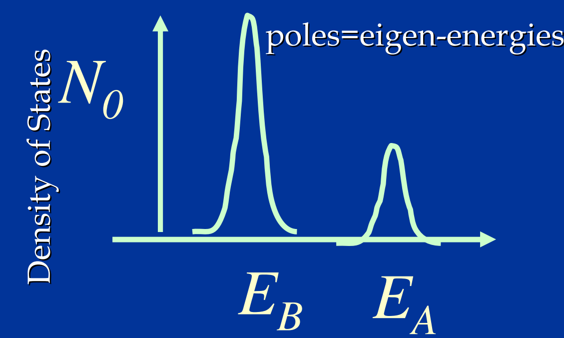
Effective Hamiltonian

$$\left(E_0 + V_{0,1}\,\frac{1}{\varepsilon - E_1}\,V_{1,0} \right) u_0 = \tilde{E}_{0\,(\varepsilon)} u_0 = \varepsilon u_0$$

Green's function

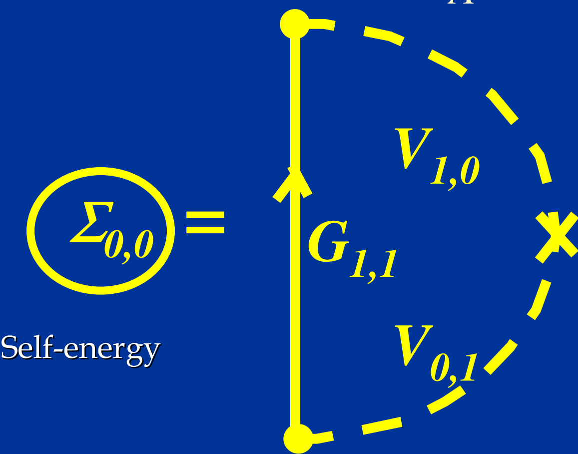
$$G^R_{0,0} = \frac{1}{\varepsilon - \tilde{E}_0} = \frac{1}{\varepsilon - E_0 - V_{0,1}\,\frac{1}{\varepsilon - E_1}\,V_{1,0}}$$

Σ_0 Self-energy



Series expansion: The Dyson Equation

$$\begin{aligned} G^R_{0,0} &= G^{(0)R}_{00} + G^{(0)R}_{00}\, V_{0,1}\, G^{(0)R}_{1,1}\, V_{1,0}\, G^{(0)R}_{0,0} + \ldots \\ &= G^{(0)R}_{00} + G^{(0)R}_{00}\, \Sigma^R_0\, G^{(0)R}_{0,0} + \ldots \\ &= G^{(0)R}_{00} + G^{(0)R}_{00}\, \Sigma^R_0\, G^R_{0,0} \end{aligned}$$



Tuning the through-bond interaction in a two-center problem.

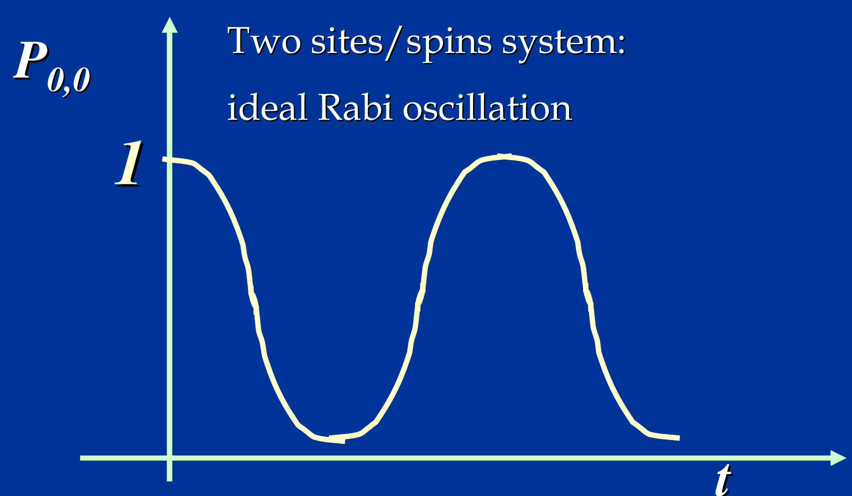
PR Levstein, HMP and JL D'Amato JPCM 2, 1781 (1990)

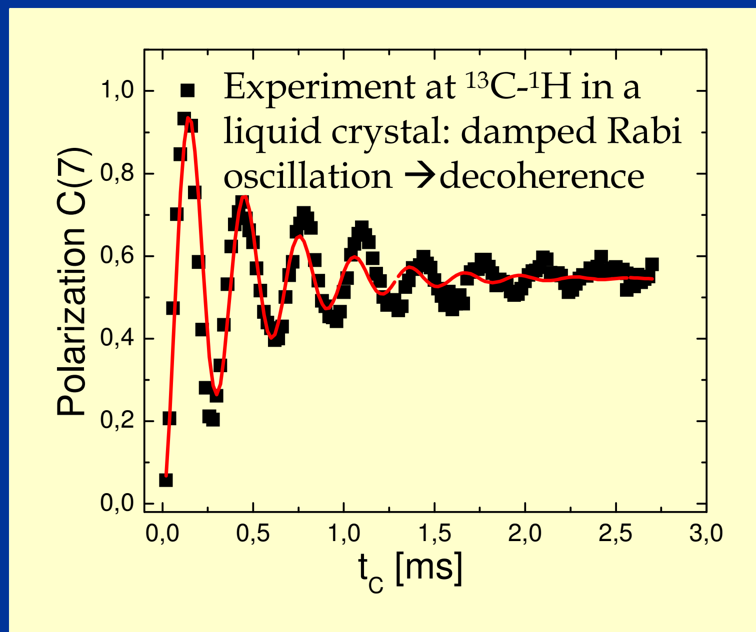
Simple Quantum Dynamics

$$\tilde{\mathbf{H}}_{01} = \begin{pmatrix} \tilde{E}_0 & \tilde{V}_{0,1} \\ \tilde{V}_{1,0} & \tilde{E}_1 \end{pmatrix}$$

$$\mathbf{G}^R = \left[\varepsilon \mathbf{I} - \tilde{\mathbf{H}}_{01}\right]^{-1}$$

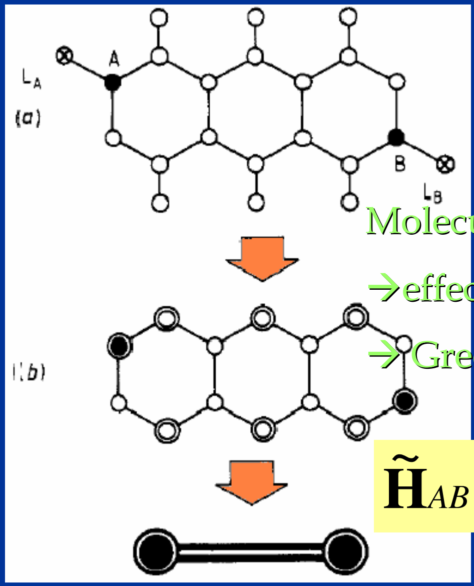
$$P_{0,0}(t) = \left| \int_{-\infty}^{\infty} \frac{\mathrm{d}\,\varepsilon}{2\pi\hbar} e^{-\mathrm{i}\varepsilon t/\hbar} G_{0,0}(\varepsilon) \right|^2$$





Levstein, Chattah, HMP J.Chem.Phys. **121**, 7313 (2004) related problems

electron transfer k_{BA}



Molecule

→effective Hamiltonian

→Green's Function

$$\tilde{\mathbf{H}}_{AB} \rightarrow G^{R}_{AB}(\varepsilon)$$

Tuning the through-bond interaction in a two-centre problem J. Phys.: Condens. Matter **2** (1990) 1781–1794.

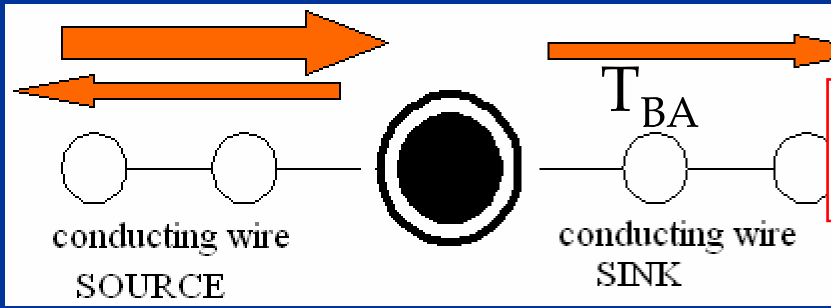
P R Levstein†, H M Pastawski‡ and J L D'Amato

Instituto de Desarrollo Tecnológico para la Industria Química, Güemes 3450, 3000 Santa Fe, Argentina

Received 16 May 1989, in final form 22 September 1989

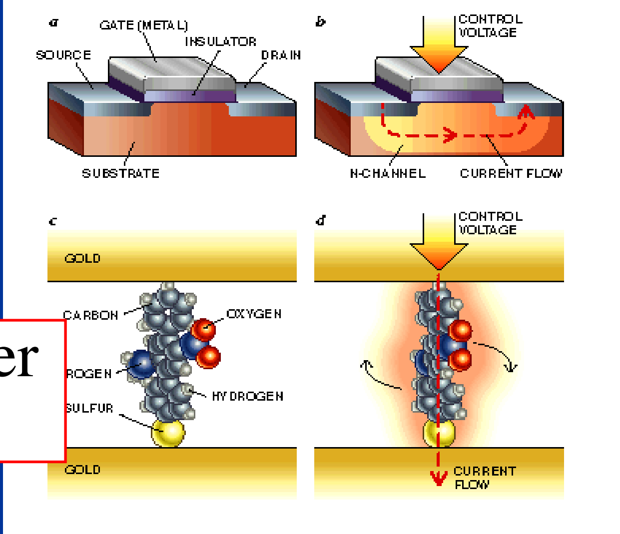
Abstract. Two centres A and B connected by one or more sets of bridging states (pathways) define a graph in the space of states. The Hamiltonian is decimated in this space and the problem is reduced to that of two sites with corrected energies $\tilde{E}_A$ and $\tilde{E}_B$ and an effective interaction $\tilde{V}_{AB}$. The goal of the method is to make evident how the pathways should be modified in order to tune the resulting coupling. The condition for maximum coupling is $\tilde{E}_A = \tilde{E}_B$ (resonance) and is related to a generalised reflection–inversion symmetry while the coupling minimises if $\tilde{V}_{AB} = 0$ (anti-resonance). This is a non-trivial situation allowed by the topology of the system which occurs when two or more pathways interfere destructively. The effects of resonances and anti-resonances in electron transfer and other applications are discussed.

molecular electronics



Rolf Landauer

1/R=e²/h T



CONVENTIONAL MICROTRANSISTOR (a) has three terminals, known as the source, gate and drain. A positive voltage applied to the gate draws electrons to the insulator (b), enabling current to flow from the source to the drain. A molecule based on three benzene rings (c) was also used to switch an electric current. The center ring had asymmetric fragments, enabling it to be twisted by an electrical field (d). With a specific voltage applied, the electrical field twisted the molecule and permitted current to flow.

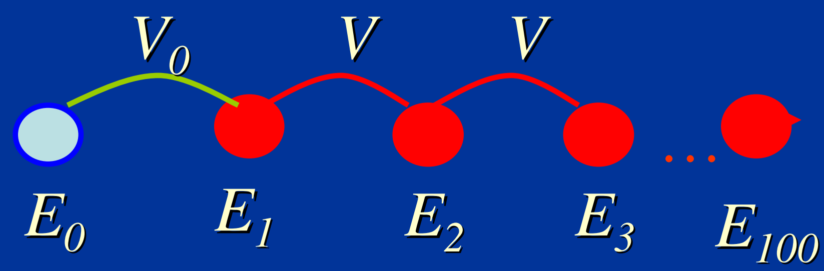
$$k_{BA} \propto T_{BA} \propto \left| G^{R}_{BA}(\varepsilon) \right|^2$$

Conductance is Transmittance

Transmittance and kinetic constant are prop. Green's Function

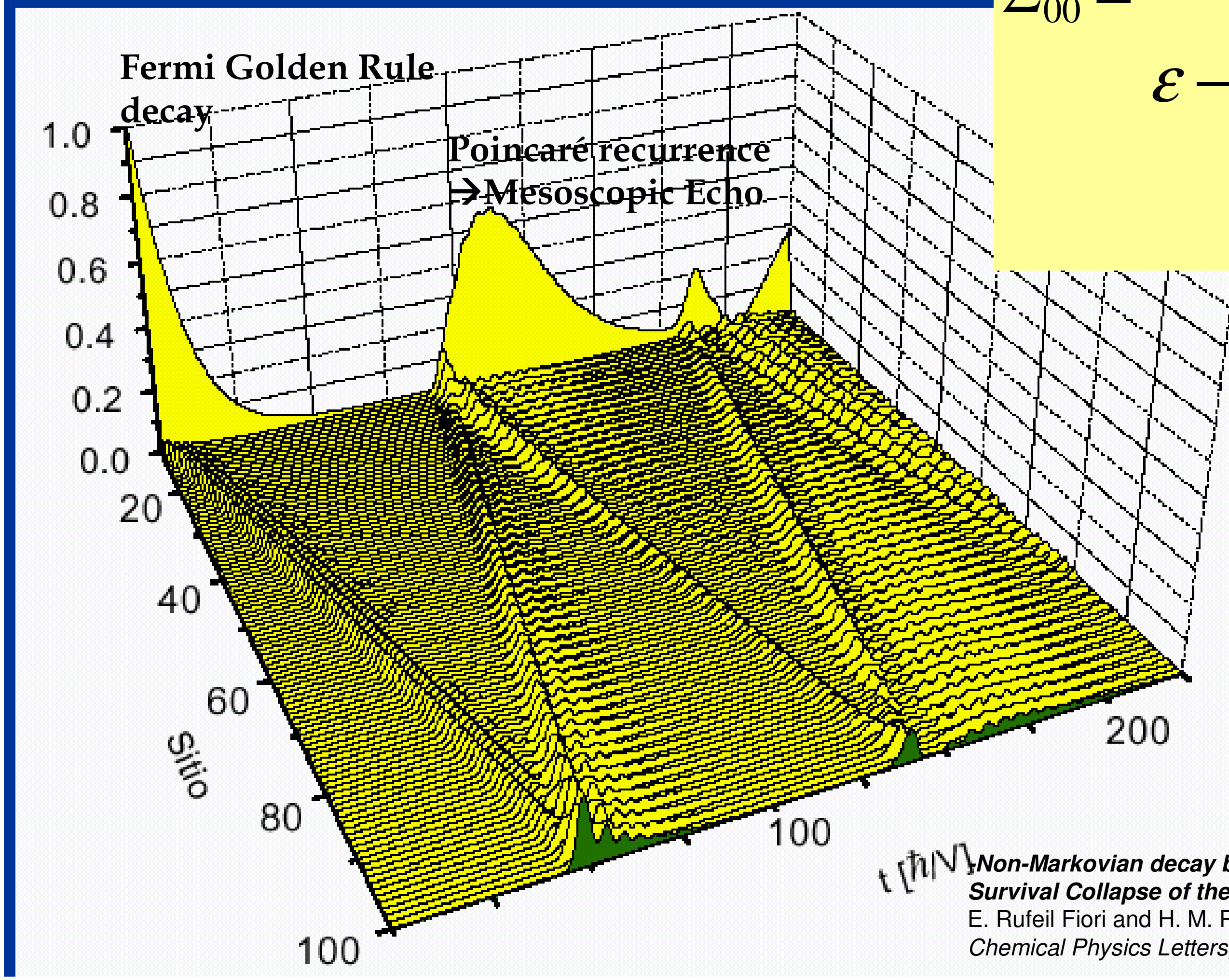
finite chain: real self-energy

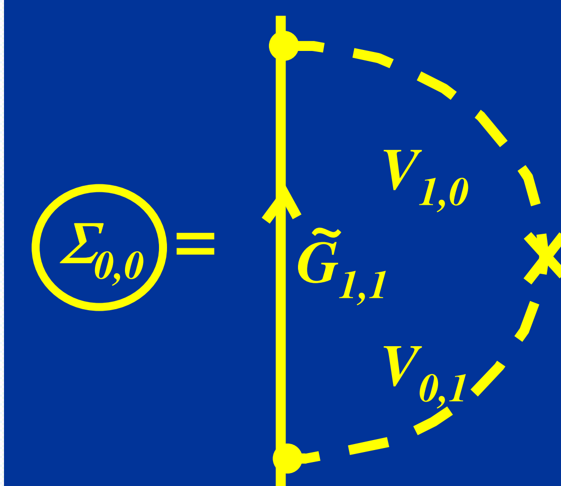
Matrix Continued-Fraction Calculation of Localization Length.
H.M.Pastawski, J.F.Weisz and S.Albornoz
Physical Review B **28**, 2896-2903 (1983)



$$\tilde{E}_0 = E_0 + \Sigma_{00}$$

$$\Sigma_{00} = \cfrac{V_0^{\,2}}{\varepsilon - E_1 - \cfrac{V^2}{\varepsilon - E_2 - \ldots\ldots \cfrac{V^2}{\varepsilon - E_{100}}}}$$





Non-Markovian decay beyond the Fermi Golden Rule: Survival Collapse of the polarization in spin chains.
E. Rufeil Fiori and H. M. Pastawski
*Chemical Physics Letters, **420**, 35-41 (2006)*

spin → fermion + Keldysh formalism

Danieli,HMP, Levstein Chem. Phys. Lett. 2003 and 2004

Polarization site at site f when injected at i:

$$P_{f,i}(t) = \frac{\left\langle \Psi_0 \left| \hat{S}_f^z(t) \hat{S}_i^z(0) \right| \Psi_0 \right\rangle}{\left\langle \Psi_0 \left| \hat{S}_i^z(0) \hat{S}_i^z(0) \right| \Psi_0 \right\rangle},$$

$$\left| \Psi_0 \right\rangle = \sum_N a_N \left| \Psi_0^{(N)} \right\rangle$$

→ thermodynamical many-body equilibrium state constructed by adding states with different number N of spins up with appropriate statistical weights and random phases.

Jordan-Wigner,

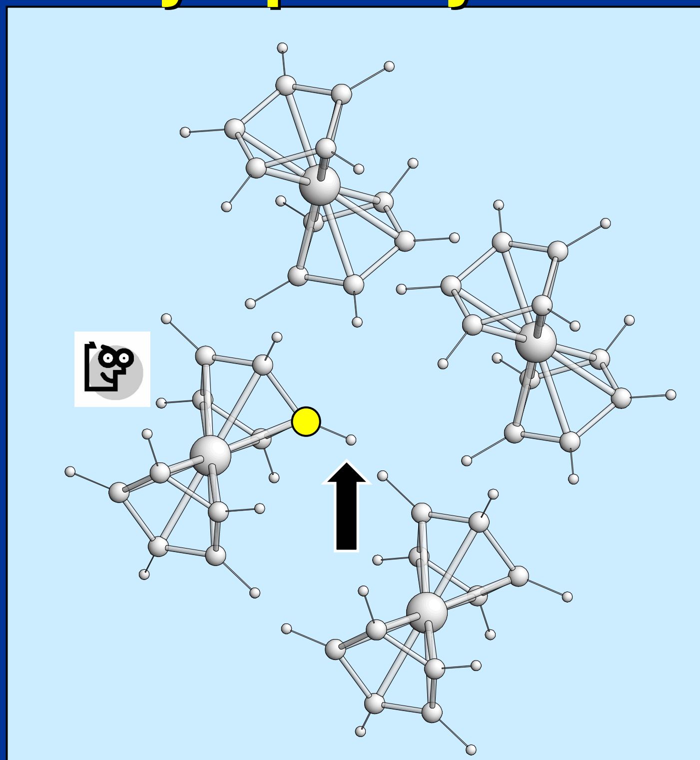
temperature $k_B T \gg J$

$$\hat{S}_n^z(t) = \hat{c}_n^+(t)\hat{c}_n(t) - \tfrac{1}{2}$$

$$G^<(X_2, X_1) = -\mathrm{i}\hbar \left[\overbrace{\left\langle \Psi(X_2)\, \Psi^*(X_1) \right\rangle}^{\text{"density"}} \right]$$

$$P_{f,i}(t) = \frac{\left\langle \Psi_0 \left| \hat{S}_f^z(t) \hat{S}_i^z(0) \right| \Psi_0 \right\rangle}{\left\langle \Psi_0 \left| \hat{S}_i^z(0) \hat{S}_i^z(0) \right| \Psi_0 \right\rangle} = -\mathrm{i}\hbar 2 G_{f,f}^<(t,t) - 1$$

many-spin dynamics➔ quantum spin "diffusion"

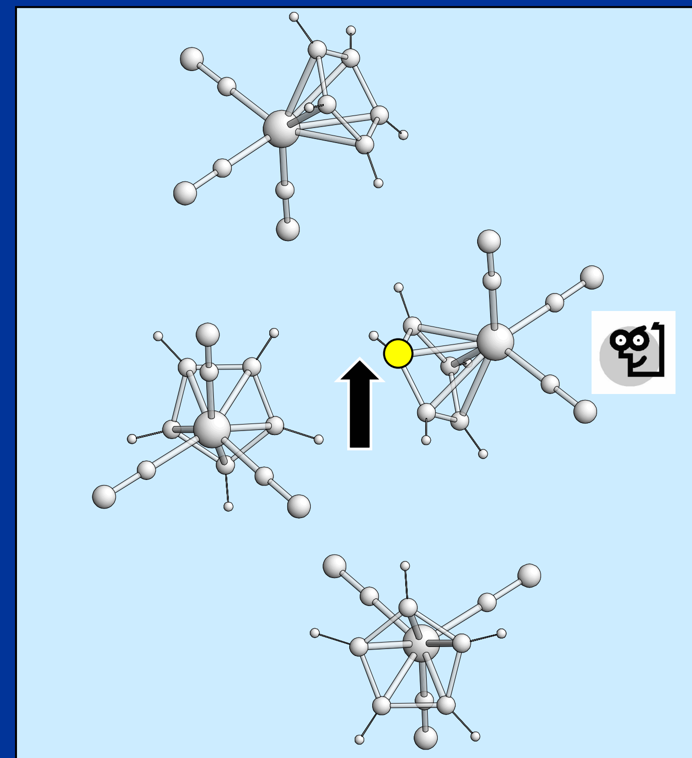


a ^{13}C

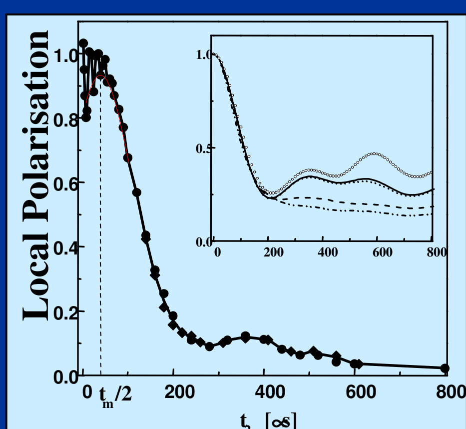
"spies"

the ^{1}H

spin



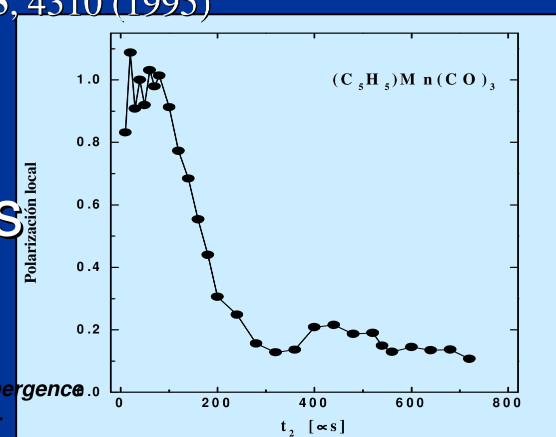
HMP, Levstein, Usaj, Phys.Rev.Lett. **75**, 4310 (1995)



finite ring size

➔mesoscopic echoes

+…decoherence



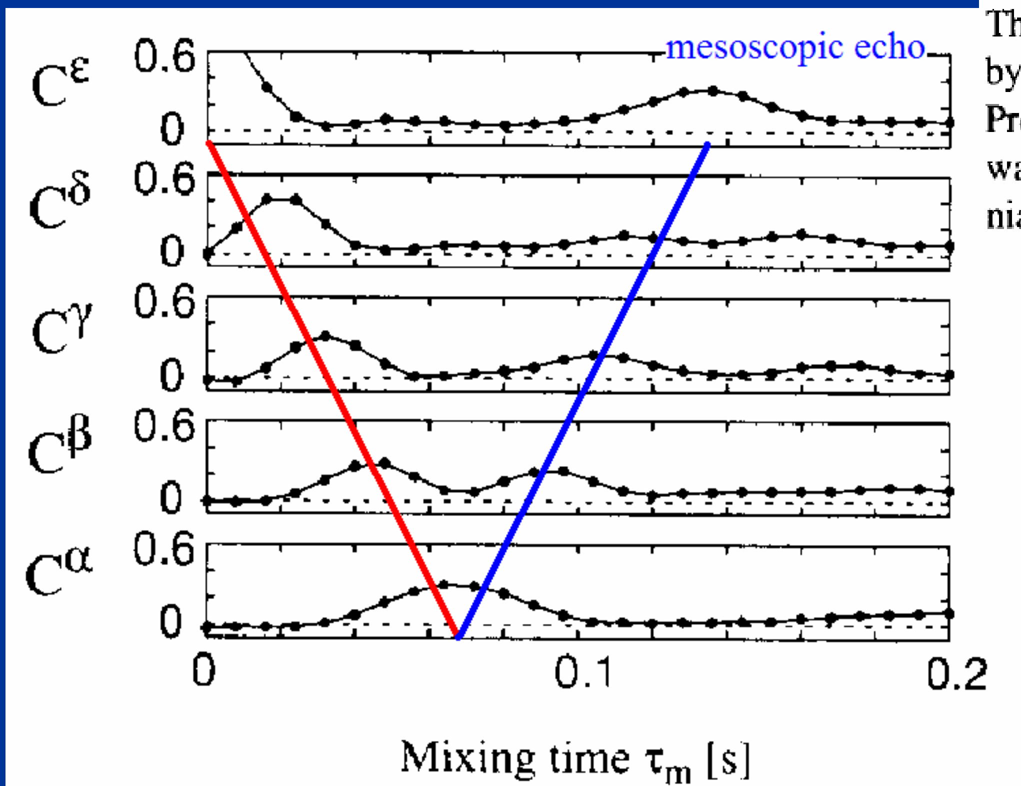
Attenuation of polarization echoes in NMR: A test for the emergence of Dynamical Irreversibility in Many-Body Quantum Systems.
P.R. Levstein, G. Usaj, HMP
J. Chem. Phys. ***108**, 2718-2724 (1998)*

Mesoscopic Echoes: NMR experiments

Time-resolved observation of spin waves in a linear chain of nuclear spins

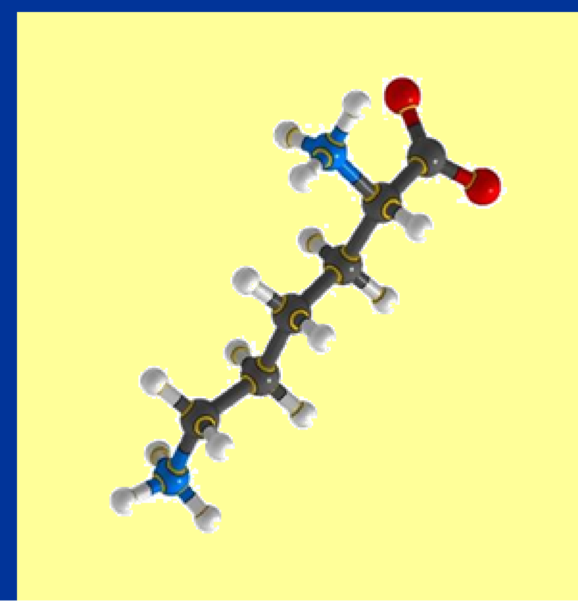
Z.L. Mádi, B. Brutscher, T. Schulte-Herbrüggen, R. Brüschweiler, R.R. Ernst

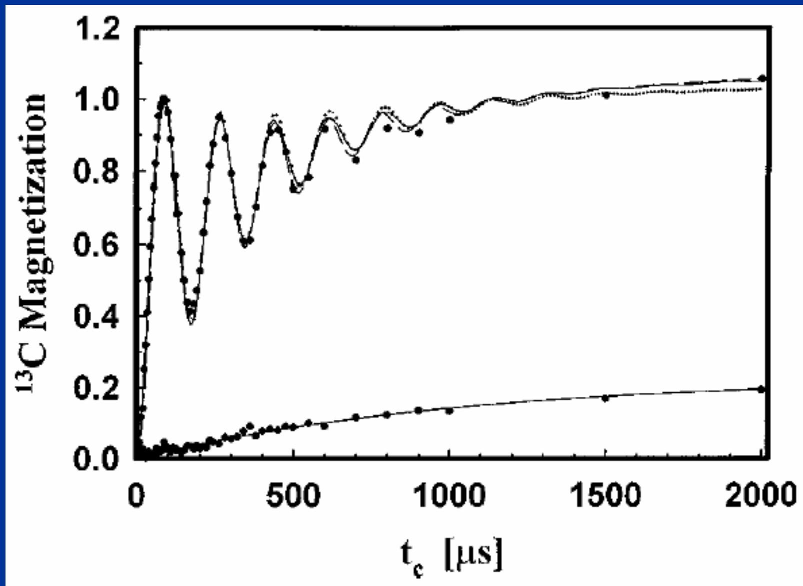
Laboratorium für Physikalische Chemie, ETH Zentrum, 8092 Zürich, Switzerland

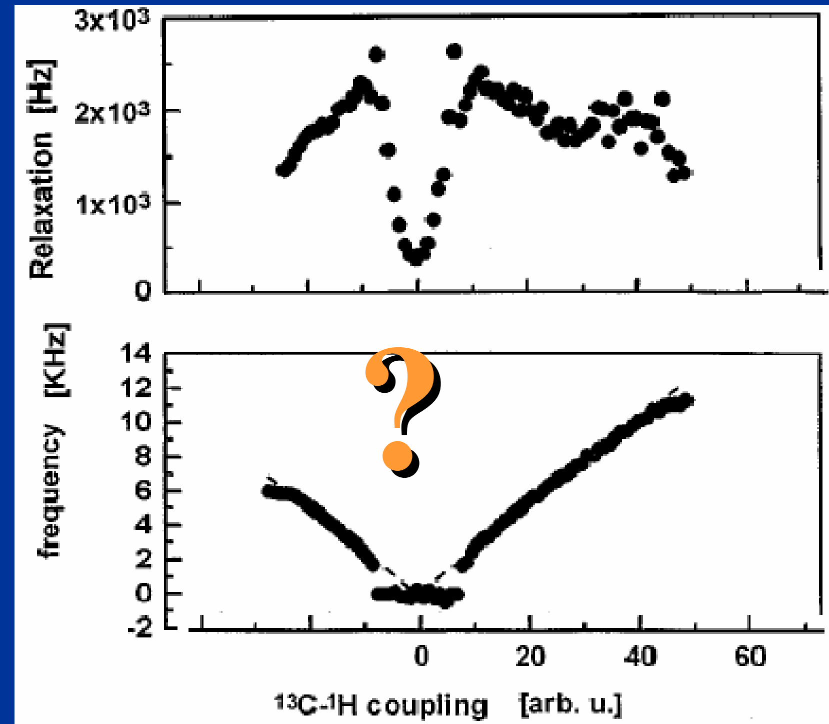


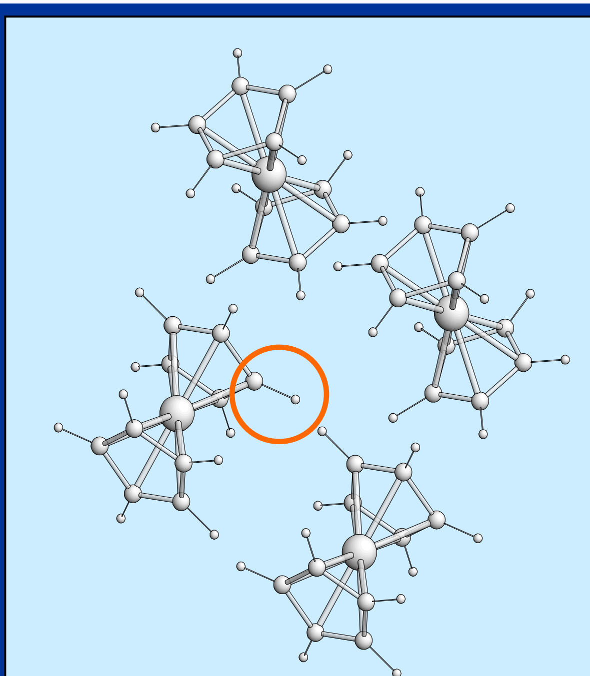
The study described in this letter has been inspired by discussions with Professor H.M. Pastawski and Professor P.R. Levstein who calculated nuclear spin wave evolution under a 'planar' or 'XY' Hamiltonian [3].

lysine









“ideal ^{13}C-^{1}H spin-swap gate”

evolves isolated

but… *^{13}C-^{1}H* interacts

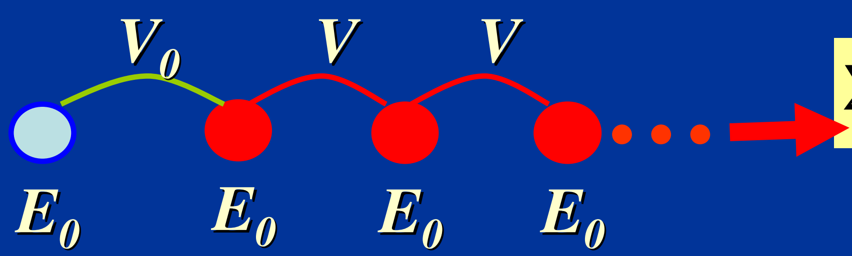
with *^{1}H* spin bath

NMR Quantum Dynamics → fermions

Effective Hamiltonian for OPEN Systems

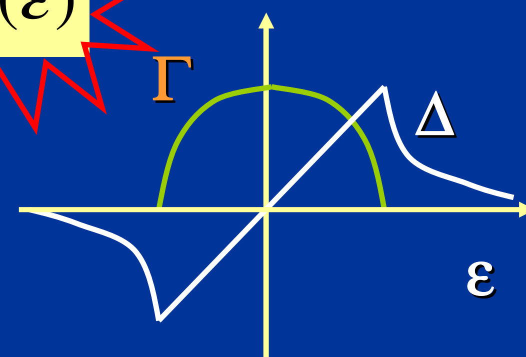
Ordered chain → Lead

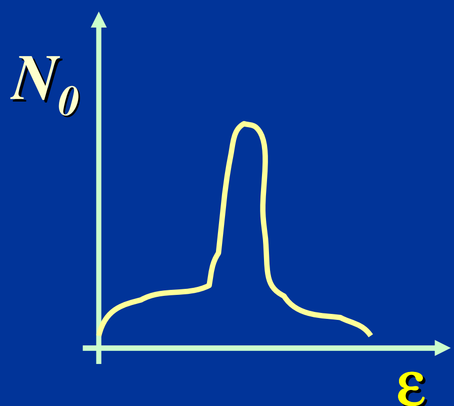
$$G^{R}_{0,0} = \frac{1}{\varepsilon - E_0 - \Sigma^R}$$

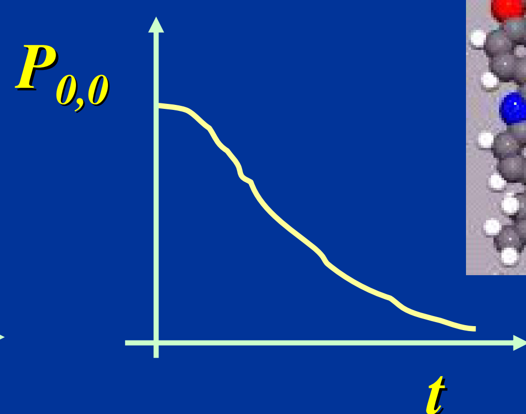


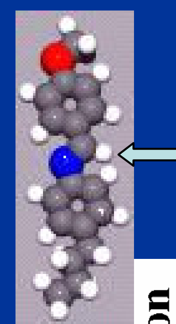
$$\Sigma^R = \Delta(\varepsilon) - \mathrm{i}\,\Gamma(\varepsilon)$$

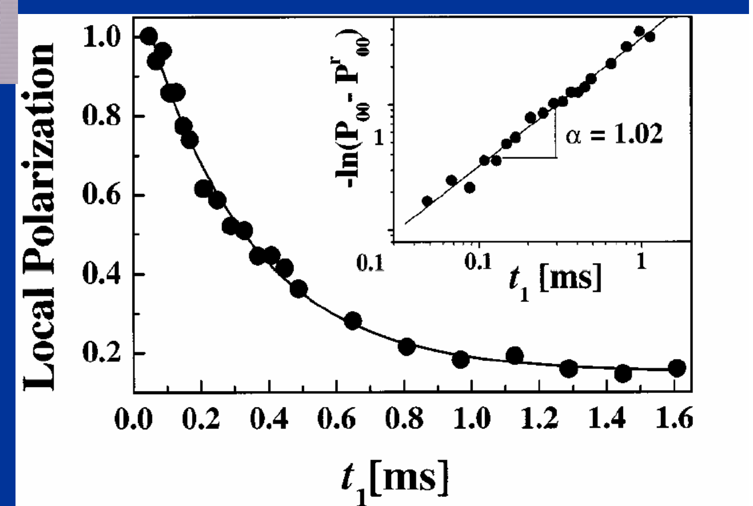
self-energy→complex











X-tal→Continuum spectrum

Mesoscopic echo→∞

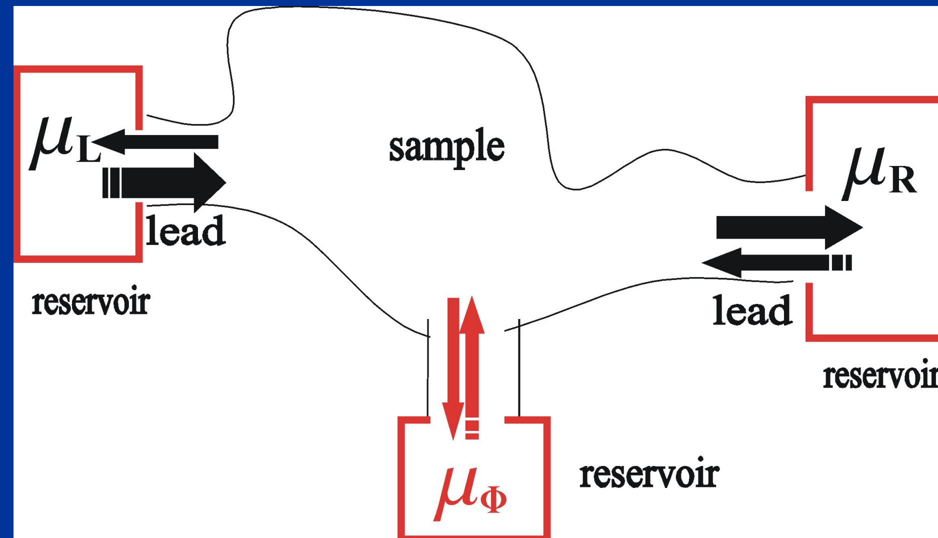
detailed dynamics Rufeil&HMP ChemPhysLett. 420,35 (2006)

but density is not conserved…!
1987

Levstein, Chattah, HMP, Raya&Hirschinger et al JCP 2004

Phenomenology of Decoherence

(Büttiker 1986)



$$\boxed{\mathrm{I}_\phi \equiv 0}$$

voltmeter

$$0 = \frac{e}{h} T_{\phi,L} (\delta\propto_\phi - \delta\propto_L) + \frac{e}{h} T_{R,\phi} (\delta\propto_\phi - \delta\propto_R)$$

$$\mathrm{I}_R = \frac{e}{h} \tilde{T}_{R,L} (\delta\propto_L - \delta\propto_R)$$

$$\tilde{T}_{R,L} = T_{R,L} + \frac{T_{R,\phi} T_{\phi,L}}{T_{R,\phi} + T_{\phi,L}}$$

coherent

incoherent

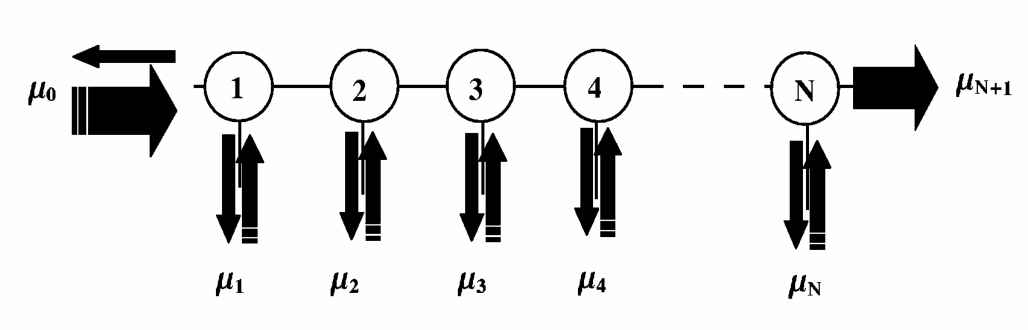
Decoherence and evolution: Keldysh=GLBE

$$T_{RL} = 2\Gamma_R \left| G^R_{RL} \right|^2 2\Gamma_L$$

Hamiltonian formulation D´Amato and HMP Phys. Rev. B **41**,7411 (1990); Datta JPCM **2**, 8023 (1990)

HMP Phys. Rev. <u>46</u> 4053 (1992) review see HMP-Medina cond-matt 0103219

- Any **imaginary energy** Γ (Fermi Golden Rule)
  requires a **thermodynamic limit** and involves "irreversible" decay" to the environment
- charge conservation → Generalized Landauer Büttiker Equations=Keldysh



$$I_i \equiv 0 = (1/g_i)\delta\propto_i - \sum_{j=0}^{N} T_{i,j}\,\delta\propto_j$$

Charge is conserved at every point i

$$\left(1/g_i\right) = \sum_{j=0}^{N} T_{j,i}$$

$$\tilde{T}_{R,L} = T_{R,L} + \sum_{i=1}^{N} T_{R,i}\, g_i T_{i,L} + \sum_{i=1}^{N}\sum_{j=1}^{N} T_{R,i}\, g_i T_{i,j}\, g_j T_{j,L} + \ldots$$

$$= T_{R,L} + \sum_{i=1}^{N} T_{R,i}\, g_i \tilde{T}_{i,L}$$

GLBE = Bethe-Salpeter

↑ *last place where a dephasing collision occured*

Keldysh in a Nutshell: GLBE Pastawski PhysRevB 92

quantum dynamics of open systems

$$\left[\overbrace{\Psi(X_2)\,\Psi^*(X_1)}^{\text{"detected general density"}}\right] = \hbar^2 \iint \underbrace{\mathrm{d}X_j\, G^R(X_2,X_j)\,[\overbrace{\Psi(X_j)}^{\text{ret. inject.}}}_{\textit{retarded}}\ \underbrace{\overbrace{\Psi^*(X_k)}^{\text{adv. inject.}}]\,G^A(X_k,X_1)\ \overbrace{\mathrm{d}X_k}^{\textit{init.coord.}}}_{\textit{advanced}}$$

with $X_i = (r_i, t_i)$

Keldysh Density Function

➔ Wigner function

= Density Matrix

$$G^<(X_2,X_1) = -\mathrm{i}\hbar\left[\overbrace{\left\langle \Psi(X_2)\ \Psi^*(X_1)\right\rangle}^{\text{"detected general density"}}\right]$$

$$G^<(X_2,X_1) = \hbar^2 \iint \overbrace{\mathrm{d}r_j}^{\textit{init.coord.}}\ G^R(X_2,r_j)\left[\overbrace{G^<(r_j,t_0;r_k,t_0)}^{\text{intial distrib.}}\right]\underbrace{G^A(r_k,X_1)\ \overbrace{\mathrm{d}r_k}^{\textit{init.coord}}}_{\textit{advanced}}$$

$$+\iint \underbrace{\overbrace{\mathrm{d}X_j}^{\textit{init.coord.}}\ G^R(X_2,X_j)}_{\textit{retarded}}\,[\overbrace{\Sigma^<(X_j,X_k)}^{\text{re-injects losses}}]\ \underbrace{G^A(X_k,X_1)\ \overbrace{\mathrm{d}X_k}^{\textit{init.coord.}}}_{\textit{advanced}}$$

$$G^<(r,r,t,\varepsilon) = \int G^<(r,t+\tfrac{1}{2}\delta t; r,t-\tfrac{1}{2}\delta t)\,\mathrm{e}^{\mathrm{i}\varepsilon\delta t/\hbar}\,\mathrm{d}\delta t \approx N_r(\varepsilon)\,\mathrm{f}_r(\varepsilon,t)$$

$$\Sigma^<(r,t) = {}^{\phi}\Gamma_r(\varepsilon)\,\mathrm{f}_r(r,\varepsilon,t)$$

$${}^{\phi}\Gamma(\varepsilon) = 2\pi V_\phi^2\, N(\varepsilon)$$

$$G^{<}_{k,l}(t_2,t_1) = \langle \Psi_{ne} | \hat{c}_k^{+}(t_1)\hat{c}_l(t_2) | \Psi_{ne} \rangle,$$

$$\Sigma^R(\varepsilon)=\Delta^R(\varepsilon)-\mathrm{i}\Gamma^R(\varepsilon).$$

$$G^{R}_{k,l}(t_2,t_1) = -\tfrac{\mathrm{i}}{\hbar}\theta(t_2-t_1)\langle \Psi | \hat{c}_k(t_2)\hat{c}_l^{+}(t_1)+\hat{c}_l(t_1)\hat{c}_k^{+}(t_2) | \Psi \rangle.$$

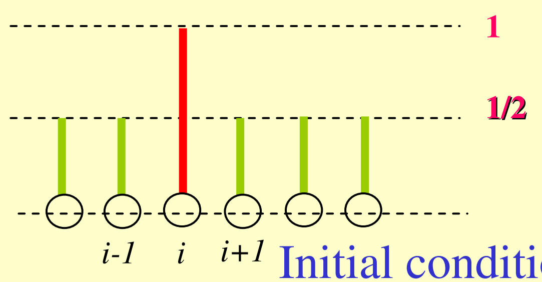
$\Sigma^R_0(\varepsilon)\approx -\mathrm{i}\Gamma_0$ $\leftarrow$ if $V_0 << V$

$$G^{<}_{n,m}(t_2,t_1) = \hbar^2 \sum_{l,k} \underbrace{G^{R}_{n,k}(t_2,0)G^{<}_{k,l}(0,0)G^{A}_{l,m}(0,t_1)}$$

$$+\sum_{k,l}\int_{t_0}^{t}\int_{t_0}^{t} \underbrace{G^{R}_{n,k}(t_2,t_k)\Sigma^{<}_{k,l}(t_k,t_l)G^{A}_{l,m}(t_l,t_1)}\,\mathrm{d}t_k\,\mathrm{d}t_l.$$

- Non-equilibrium density at $t=0$ at site i-th

$$G^{<}_{k,l}(t=0,t=0)=\tfrac{\mathrm{i}}{2\hbar}(\delta_{k,i}\delta_{i,l}+\delta_{k,l})$$



Occupation probability

Initial condition at t=0

sites

- This term would collect incoherent or coherent reinjections given by,

$$\Sigma^{<}_{0,0}(\varepsilon,t_k)=\mathrm{i}2\Gamma_0 f(\varepsilon,t_k)\delta_{k,0}\delta_{0,l}.$$

coherent Injection→

$$\Sigma^{<}_{0,0}(\varepsilon,t_k)=\int \mathrm{d}\,\delta t\ \mathrm{e}^{\mathrm{i}\varepsilon\delta t/\hbar}\ \chi_0^{*}(t_k+\tfrac{1}{2}\delta t)\chi_0(t_k-\tfrac{1}{2}\delta t)$$

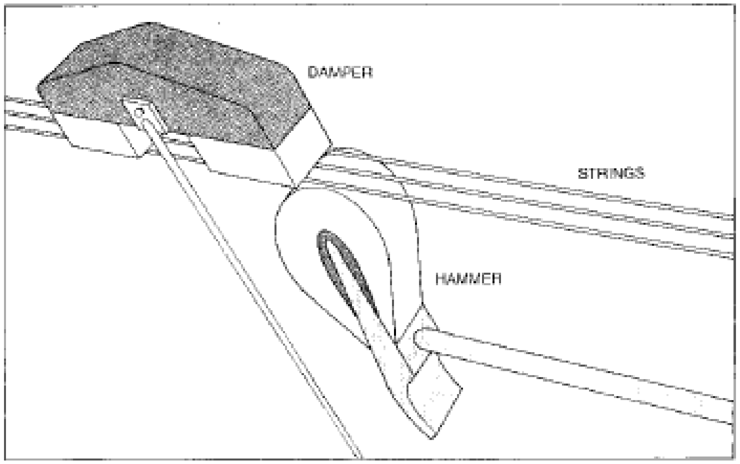
Two oscillators interacting through the environment:

The Piano Lesson

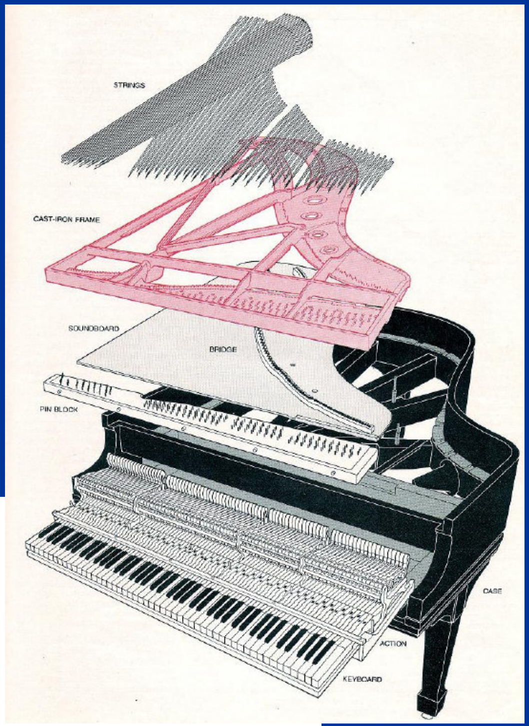
Coupled piano strings

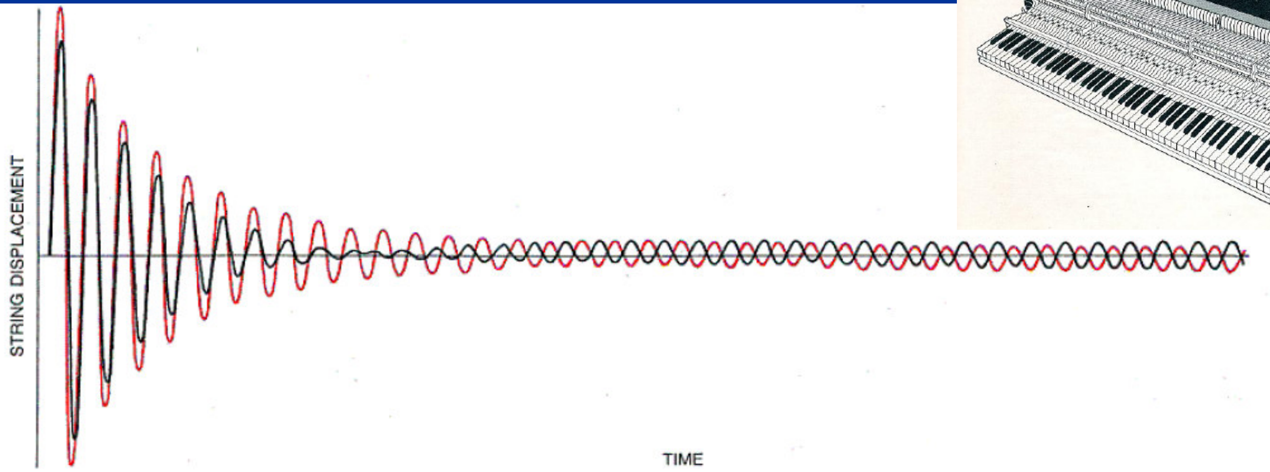
Gabriel Weinreich

1474 J. Acoust. Soc. Am., Vol. 62, No. 6, December 1977



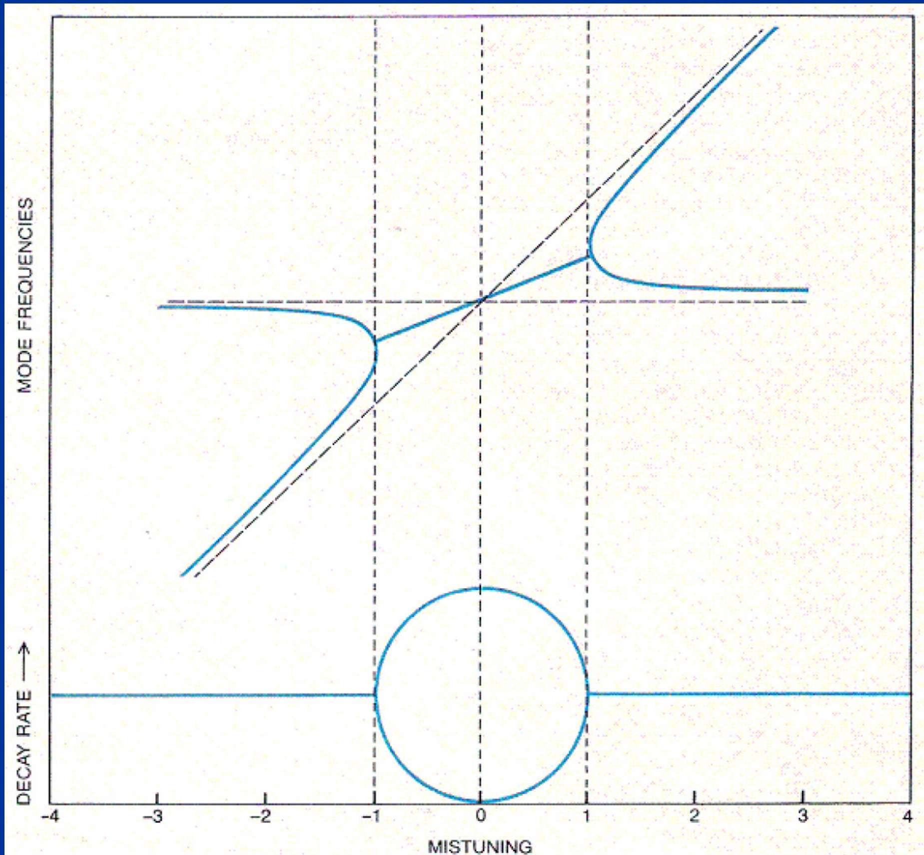
HAMMER HITS THE STRINGS that correspond to one note with the same strength and at the same time. Because the hammer strikes the strings in the vertical direction, they move mostly in that direction. They also move, however, a little in the horizontal direction. This motion could be caused by small irregularities in the face of the hammer or the position of the strings.





HAMMER IMPERFECTIONS can result in string amplitudes that are not absolutely equal. Here two strings are set in motion at the same time but with the colored string having a larger amplitude than the black one. The motions of the strings start to decay, and when the amplitude of the black string approaches zero, the bridge continues to move because it is still being forced to do so by the colored string. As a result the black string not only reaches zero amplitude but also goes "beyond" it, building up a vibration of the opposite phase by absorbing energy from the bridge. Ultimately the motions are exactly antisymmetric. Such antisymmetric motion gives rise to aftersound.

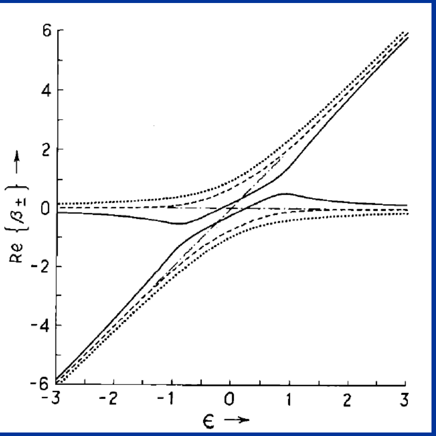
The piano lesson (cont.)



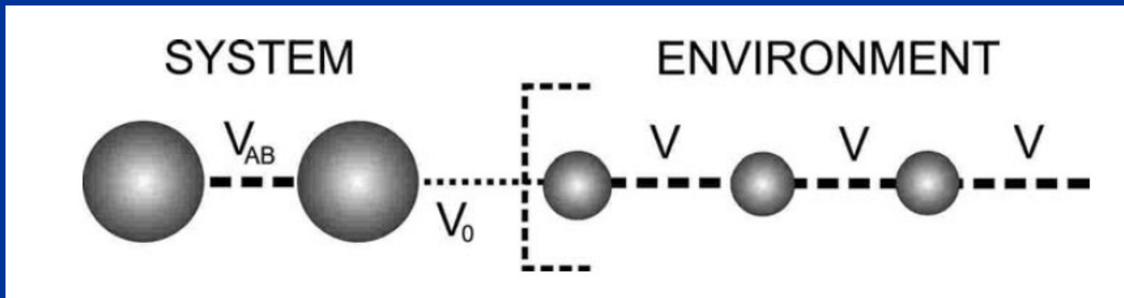
FREQUENCIES OF A PAIR OF STRINGS lock together when the motions of the strings are coupled through a purely resistive support. The mistuning, or difference between the uncoupled frequencies, is given in "natural units," which are related to the single-string damping rate. For a typical pair of strings in the middle of the keyboard, one natural unit is about a third of a vibration per second. The broken lines in the top graph indicate the frequencies in the absence of coupling. The point where the broken lines cross each other is where the two strings have exactly the same frequency. In a piano the presence of a purely resistive support causes frequencies with a mistuning of either +1 or −1 natural unit to come together and lock at a common frequency. For smaller mistunings the frequencies stay locked but the decay rate, which equals the single-string rate for larger mistunings, splits for the two strings (*bottom*).

Because of the environment…

the two strings synchronize themselves…!



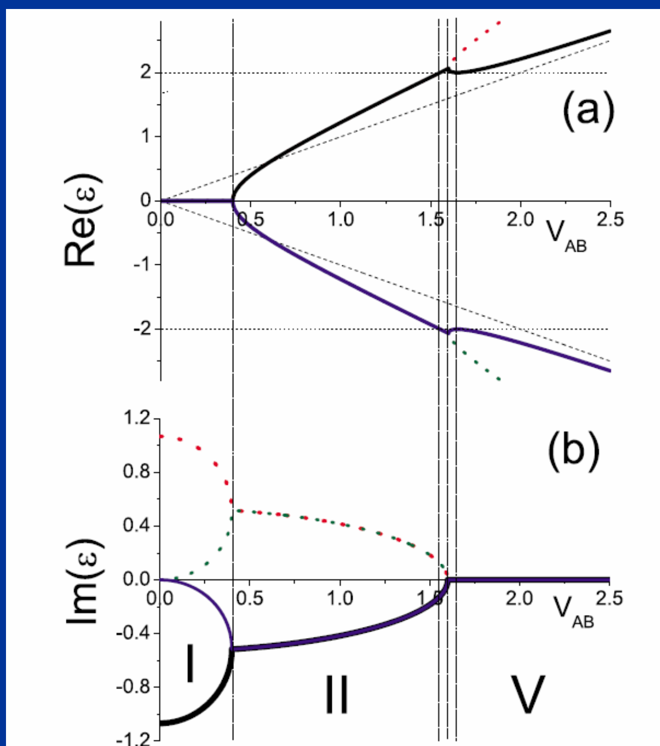
asymmetric environment



Infinite environment→FGR→Non-Hermitian effective Hamiltonian→ exceptional points in the spectrum→Quantum Dynamical Phase Transition

Ingrid Rotter 2009 *J. Phys. A: Math. Theor.* **42** 153001 **A non-Hermitian Hamilton operator and the physics of open uantum systems**

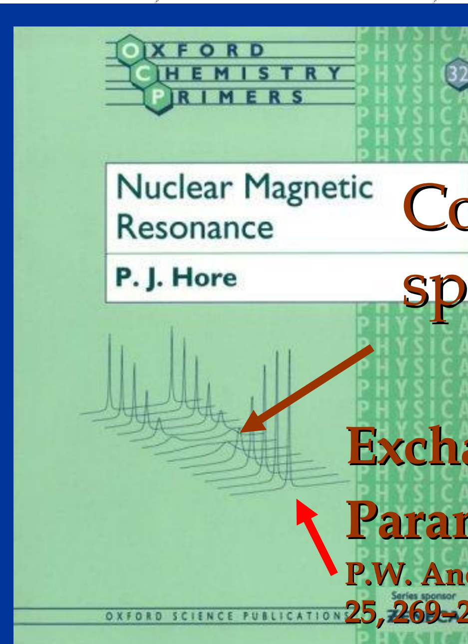
poles of the GF bifurcate



PHYSICAL REVIEW A 78, 062116 (2008)

Dynamical regimes of a quantum SWAP gate beyond the Fermi golden rule

Axel D. Dente,[1] Raúl A. Bustos-Marún,[1,2] and Horacio M. Pastawski[1]



Collapse of spectral lines

Exchange Narrowing in Paramagnetic Resonance.

P.W. Anderson and Weiss Rev. Mod. Phys. 25, 269–276 (1953)

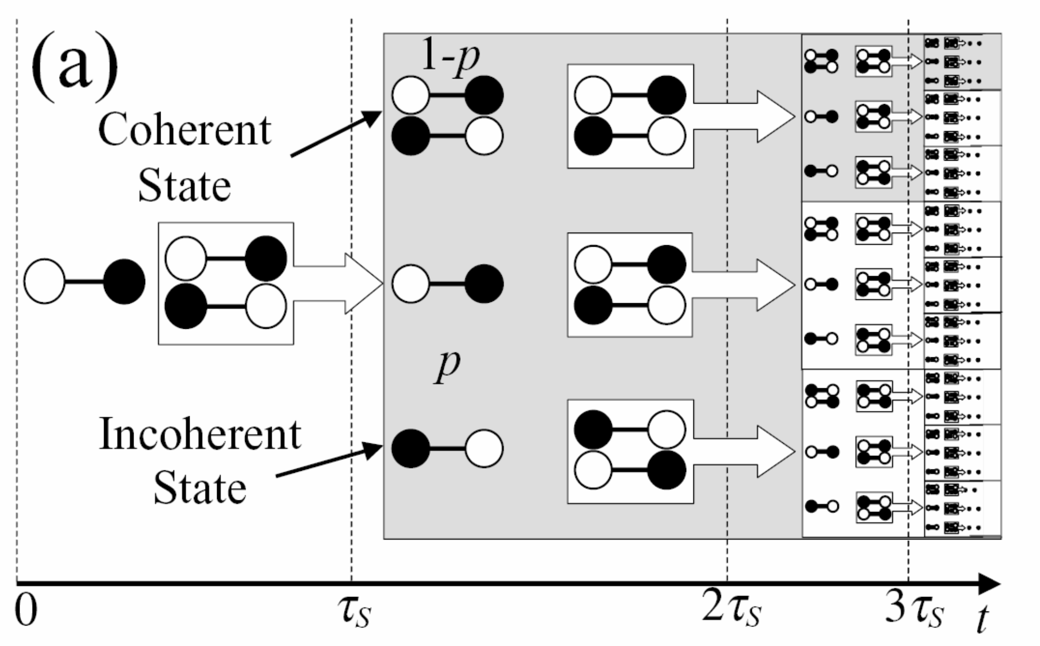
GLBE for spins: avoid memorize previous stories by using Trotter steps (**Keldysh=Quantum Jumps**).

Danieli, Álvarez, HMP CPL05;
Álvarez, Danieli, Levstein,
HMP cond-mat/0504347

$$\frac{1}{\hbar^2}\mathbf{G}^{<}(t) = \mathbf{G}^{0\mathrm{R}}(t)\,\mathbf{G}^{<}(0)\,\mathbf{G}^{0\mathrm{A}}(t)\,(1-p)^{n} + \sum_{m=1}^{n}\mathbf{G}^{0\mathrm{R}}(t-t_m)\,\widetilde{\boldsymbol{\Sigma}}^{<}(t_m)\,\mathbf{G}^{0\mathrm{A}}(t-t_m)\,p\,(1-p)^{n-m}, \qquad (4)$$

$$\boldsymbol{\Sigma}_{\mathrm{m}}^{<}(t) = \mathrm{i}\frac{\hbar}{\tau_{\mathrm{SE}}}\begin{pmatrix} \frac{\hbar}{\mathrm{i}}G_{11}^{<}(t) & 0 \\ 0 & \frac{\hbar}{\mathrm{i}}G_{22}^{<}(t) \end{pmatrix}$$

$$\boldsymbol{\Sigma}_{\mathrm{i}}^{<}(t) = 2\mathrm{i}\frac{\hbar\, p_{\mathrm{XY}}}{\tau_{\mathrm{SE}}}\begin{pmatrix} 0 & 0 \\ 0 & \left[1-\frac{\hbar}{\mathrm{i}}G_{22}^{<}(t)\right] \end{pmatrix}$$



Integral GLBE-Keldysh

→simpler Trotter evolution +

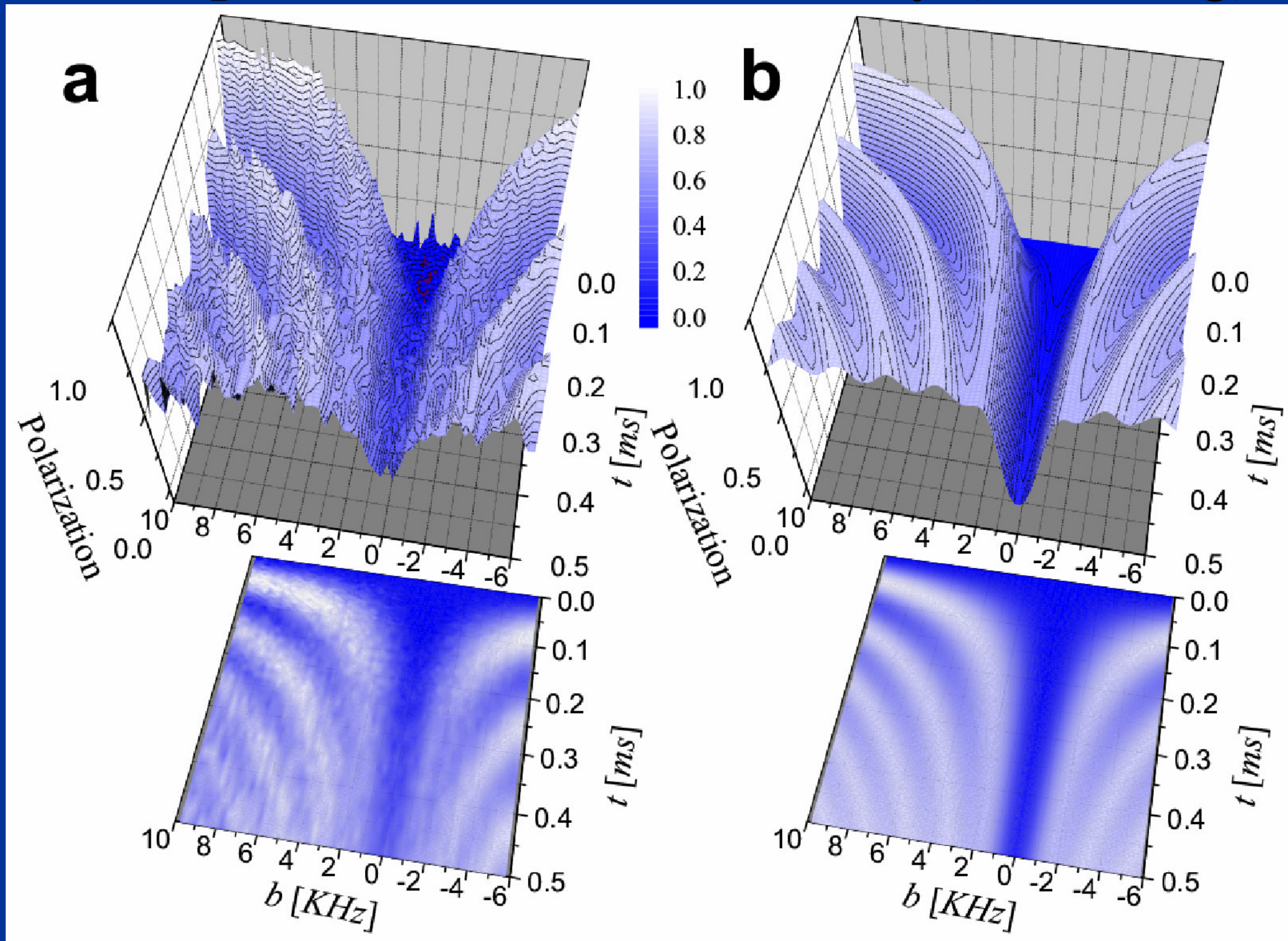
Carmichel's Quantum Jumps

PHYSICAL REVIEW A **75**, 062116 (2007)

Decoherence under many-body system-environment interactions: A stroboscopic representation based on a fictitiously homogenized interaction rate

Gonzalo A. Álvarez, Ernesto P. Danieli, Patricia R. Levstein, and Horacio M. Pastawski*

raw experimental data theory (no-fitting)



fermions + open systems+ time → Keldysh → GLBE (Landauer-Büttiker)

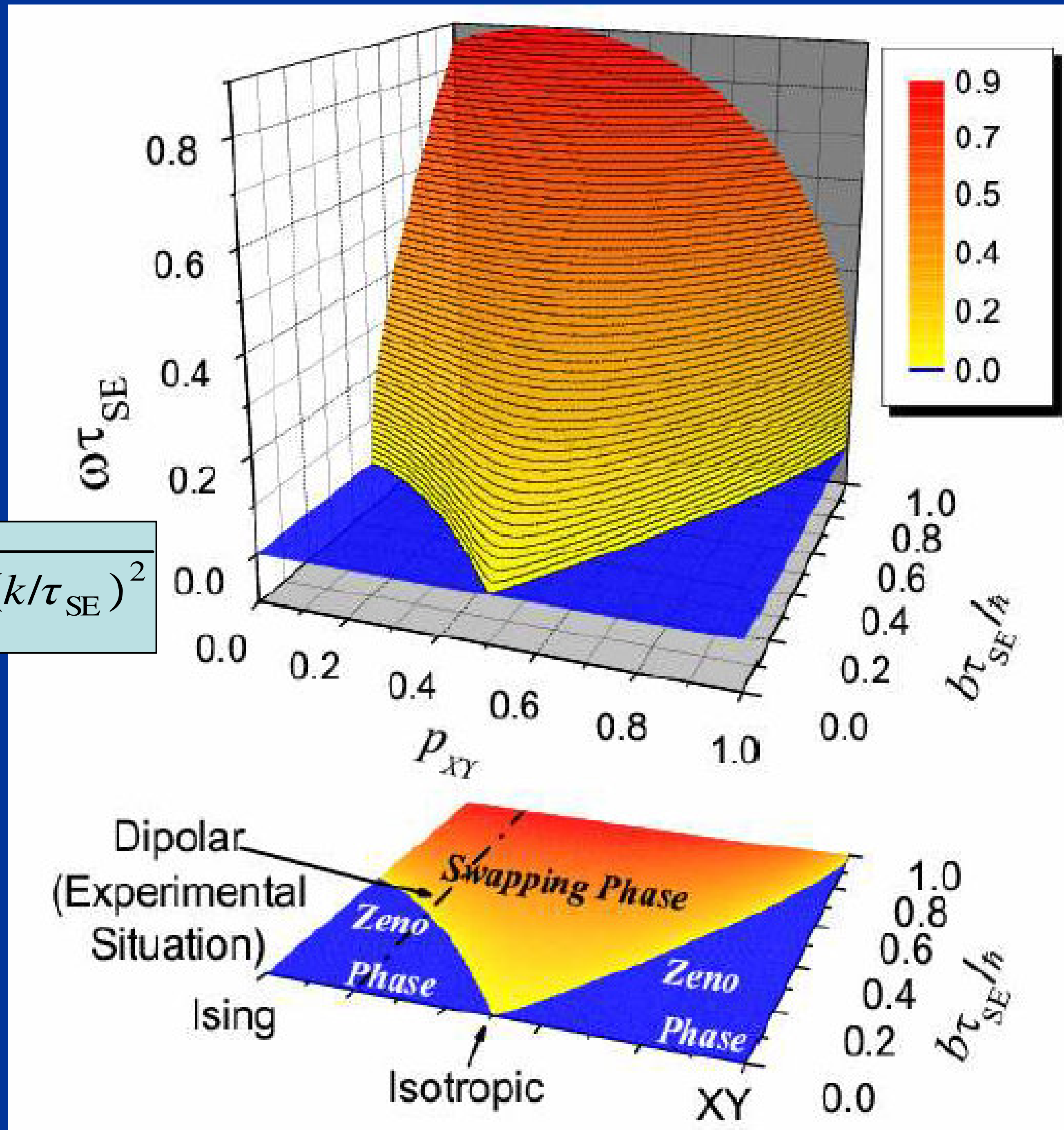
→quantum dynamical phase transition

Environmentally induced quantum dynamical phase transition in the spin swapping operation
GA Álvarez, E P Danieli, PR Levstein, and HMP J. Chem. Phys. 124, 1 (2006)

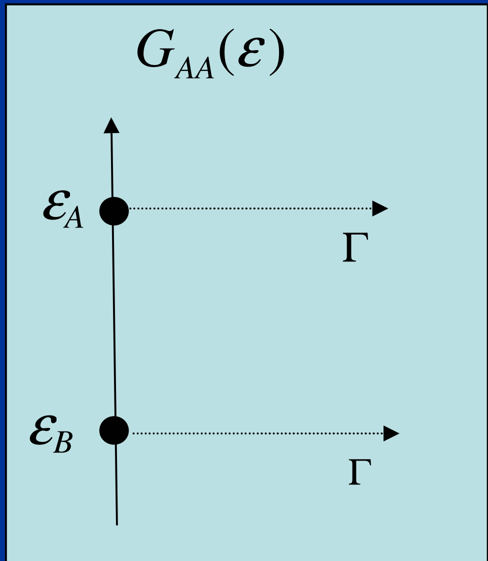
quantum dynamical phase transition

$$\omega \propto \sqrt{(b/\hbar)^2 - (k/\tau_{SE})^2}$$

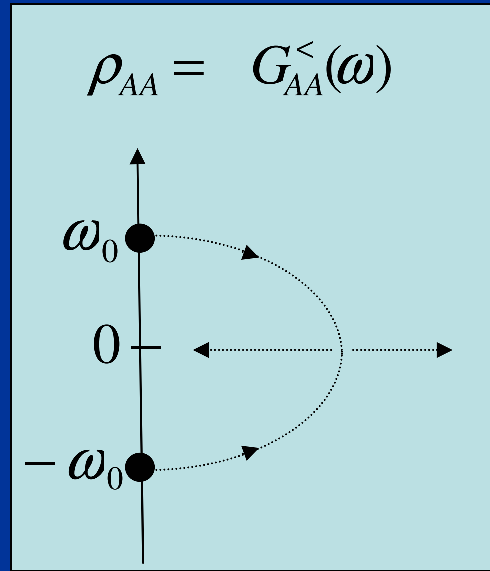
k=0 Heisenberg
k=1 XY



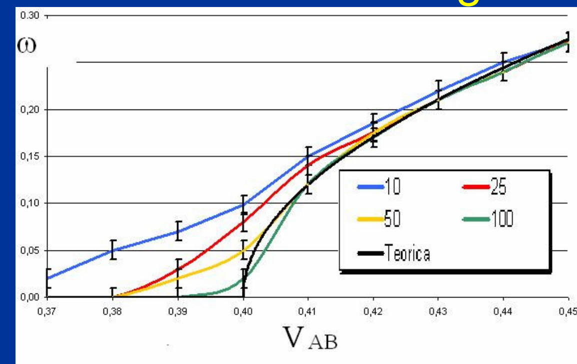
Ising interaction:
decoherence rate
and **frequency**
are **non-analytic**
on the SE interaction strength



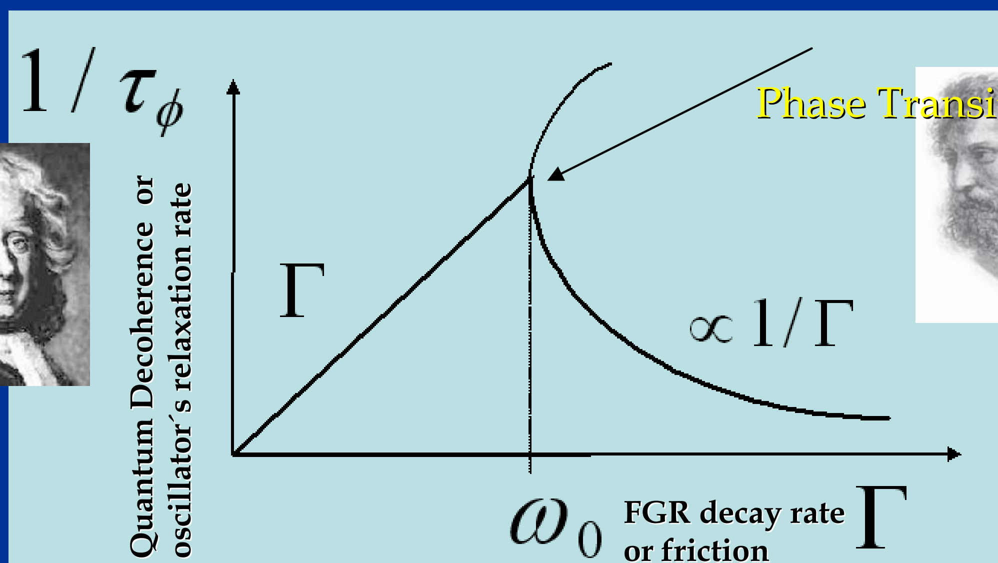
NO Phase Transition in the GF poles



GLBE solution (Density) has a Phase Transition



NO finite system has a Phase Transition



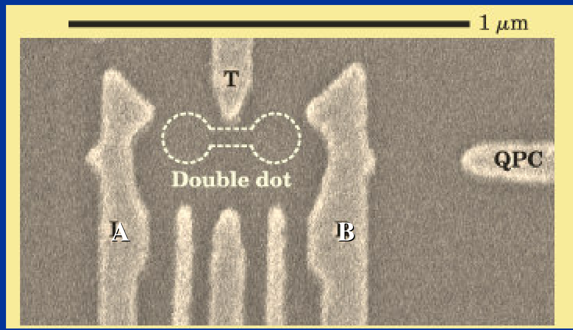
NEWTON: **Inertia** rules

Aristotle: the realm of **friction**

review on Quantum Dynamical Phase Transition and its philosophical implications:

Revisiting the Fermi Golden Rule: Quantum dynamical phase transition as a paradigm shift

HMP Physica B **398** (2007) 278

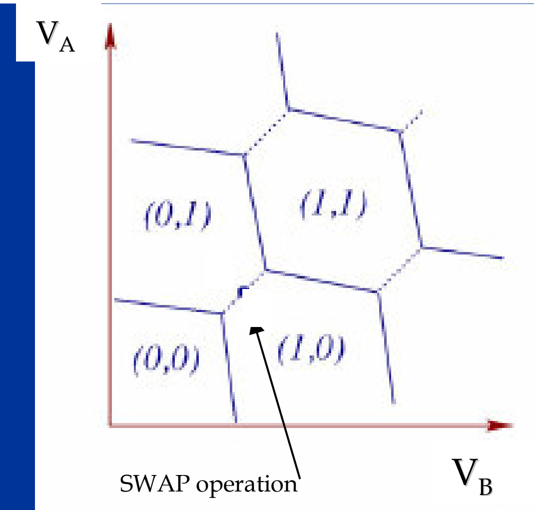


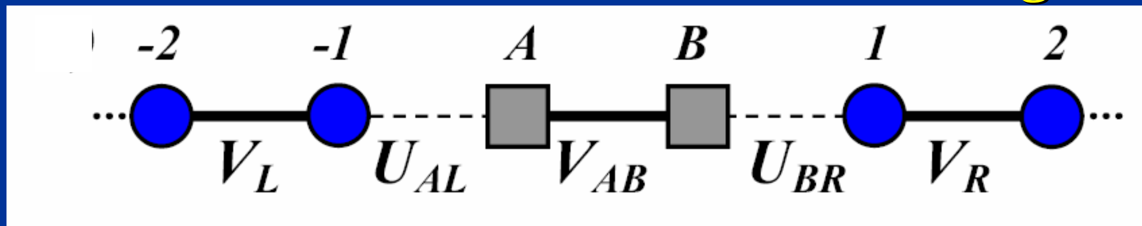
swap gate

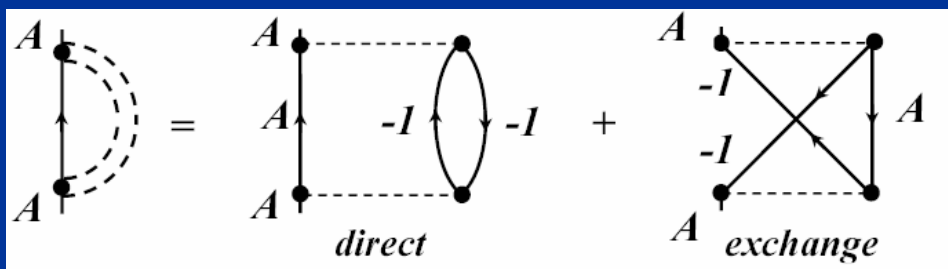
double dot charge q-bit

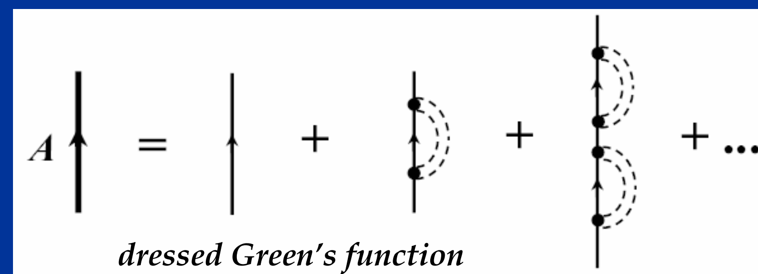
Fermions←→spins

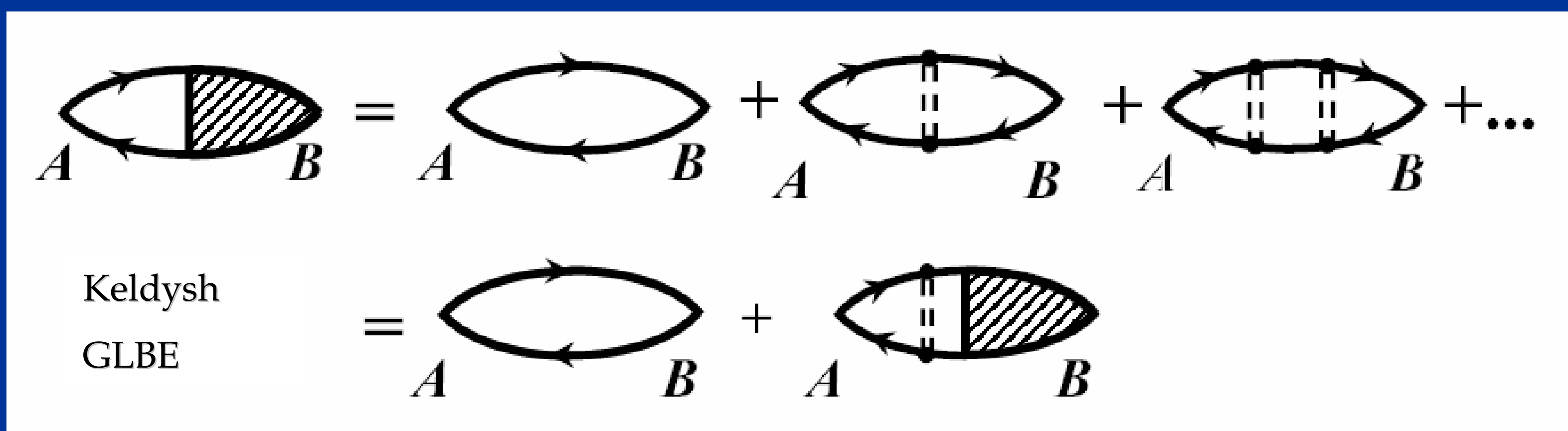
Coulomb←→Ising











Quantum dynamical phase transition in a system with many-body interactions, EP Danieli, GA Álvarez, PR Levstein and HMP, Sol.St.Comm.141,422 (2007)

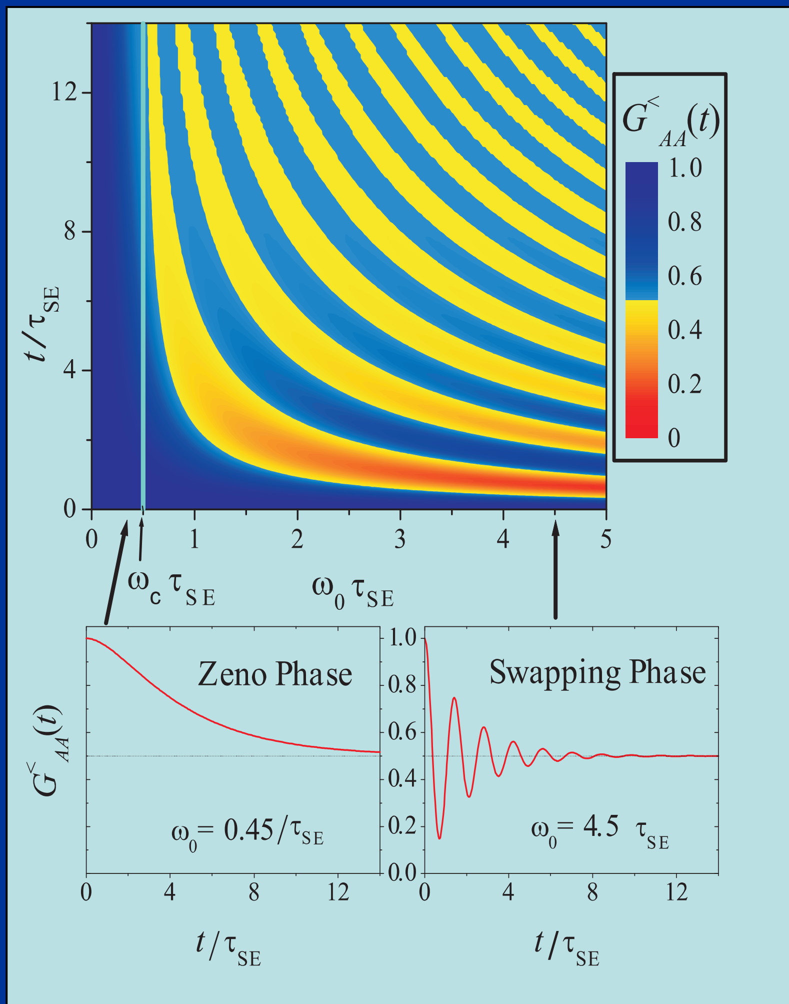
fermions

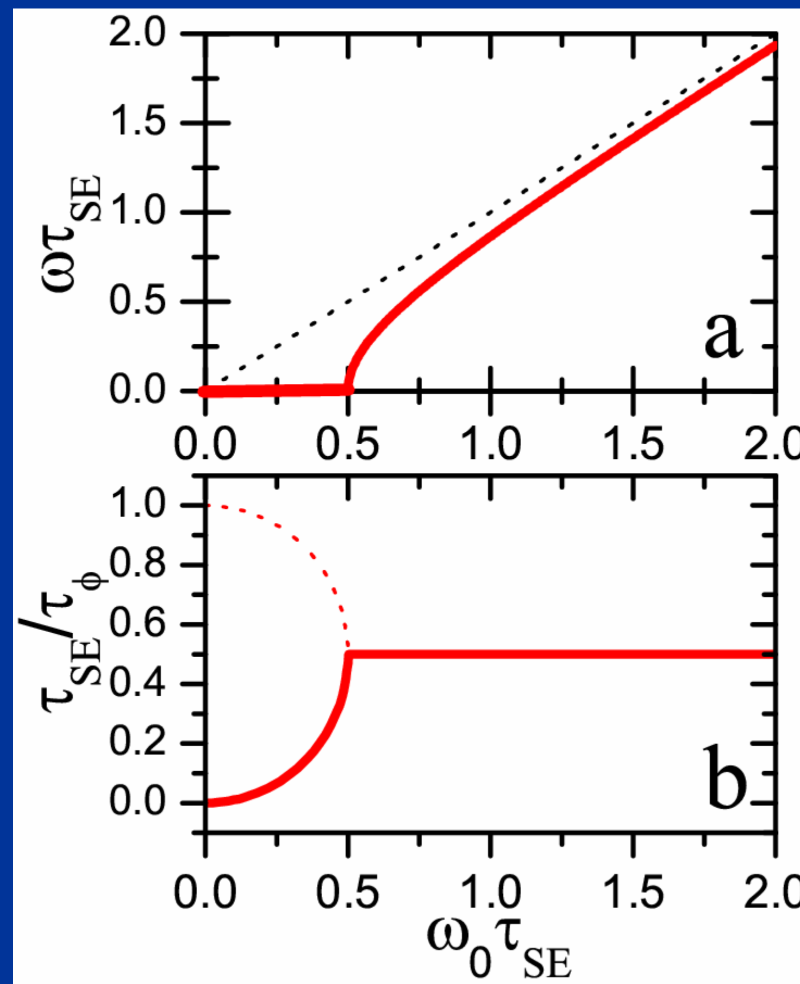
$$\omega = \begin{cases} \omega_0\sqrt{1-(2\omega_0\tau_{\mathrm{SE}})^{-2}} & \omega_0 > \frac{1}{2\tau_{\mathrm{SE}}} \\ 0 & \omega_0 \le \frac{1}{2\tau_{\mathrm{SE}}} \end{cases}$$

$$\eta = \begin{cases} 0 & \omega_0 > \frac{1}{2\tau_{\mathrm{SE}}} \\ \omega_0\sqrt{(2\omega_0\tau_{\mathrm{SE}})^{-2}-1} & \omega_0 \le \frac{1}{2\tau_{\mathrm{SE}}} \end{cases}$$

$$\begin{aligned} 1/\tau_\phi &= -\lim_{t\to\infty}\frac{1}{t}\ln\left[\tfrac{\hbar}{\mathrm{i}}G^<_{AA}(t,t)-\tfrac{1}{2}\right] \\ &= 1/\left(2\tau_{\mathrm{SE}}\right) \qquad \text{for} \quad \omega_0 \ge \frac{1}{2\tau_{\mathrm{SE}}} \end{aligned}$$

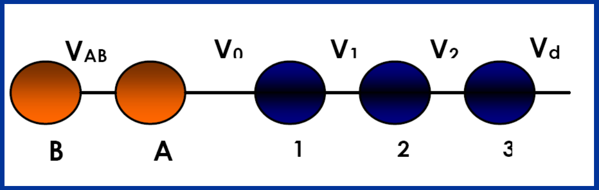
$$\begin{aligned} 1/\tau_\phi &= \frac{1}{2\tau_{\mathrm{SE}}}\left[1-\sqrt{1-(2\omega_0\tau_{\mathrm{SE}})^2}\right] \\ &\simeq \omega_0^2\tau_{\mathrm{SE}} \quad \text{for} \quad \omega_0 \ll \frac{1}{2\tau_{\mathrm{SE}}} \end{aligned}$$



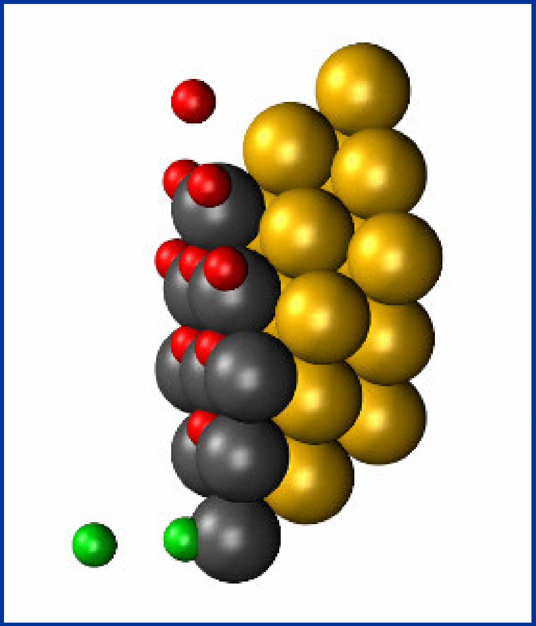


Why is Catalytic Molecular Disociación abrupt ?
a Quantum Dynamical Phase Transition…?

Axel Dente, Andrés Ruderman,
Raúl Bustos-Marún
E. Santos, W.Schmickler



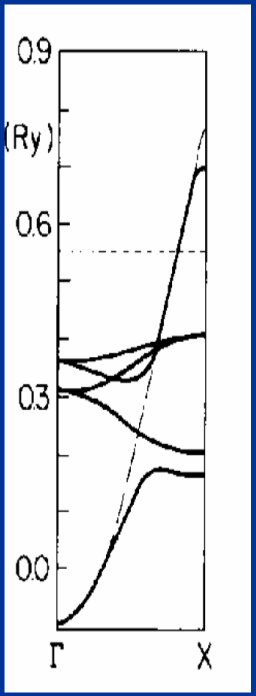
Lanczos



LDA mol. Dynamics:

H_2 molecule on top a Pt surface

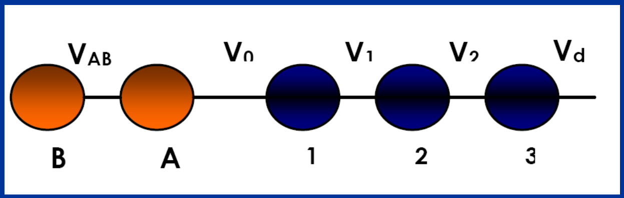
wide s-p band

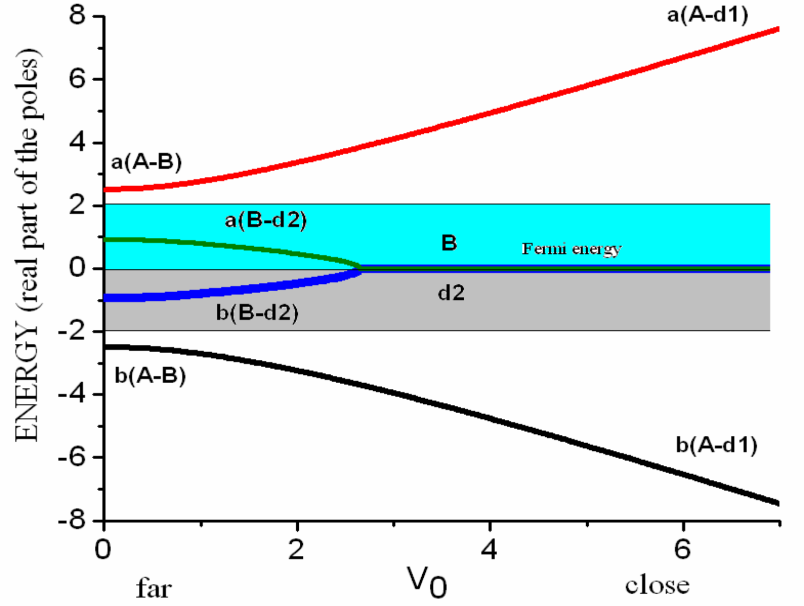


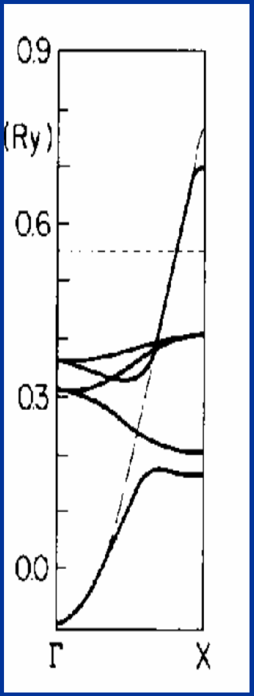
narrow d band

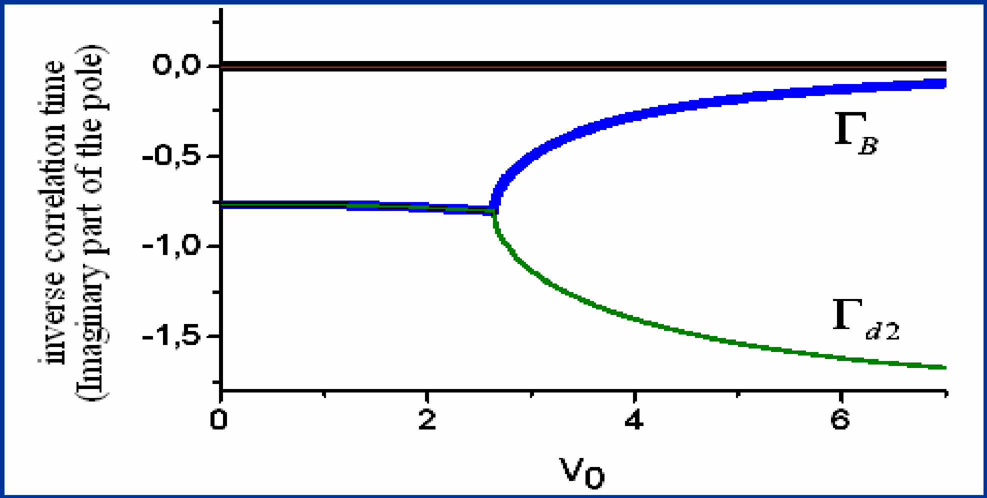
Pt band structure

Molecular Dissociation is a quantum dynamical phase transition









Summary

--We observed experimentally that the dynamics of SWAP gate has a transition to a frozen regime…! …it is consequence of the **"observation"** by the environment i.e. the **Quantum Zeno Effect.**

--Once more…as occurs with the Loschmidt Echo, the **observables are non-analytic** on the Hamiltonian parameters…
→ **quantum dynamical phase transition (bifurcation)**.

--SURPRISE: The isotropy in the spin-spin interaction hinders the transition

original work on time dependent Keldysh

Classical and Quantum Transport from Generalized Landauer-Büttiker Equations I *and* ***II: Time dependent tunneling.*** HMP *Phys.Rev.* B **44** 6329(1991); *Phys.Rev.*B **46** 4053 (1992)

review on Green's functions:

`Tight Binding' methods in quantum transport through molecules and small devices: From the coherent to the decoherent description. HMP and E. Medina *Rev. Mex. Fisica* **4 7s1**, 1-23 (2001) cond-mat/0103219

review on FGR and Quantum Dynamical Phase Transition:

Revisiting the Fermi Golden Rule: Quantum dynamical phase transition as a paradigm shift
HMP Physica B **398** (2007) 278