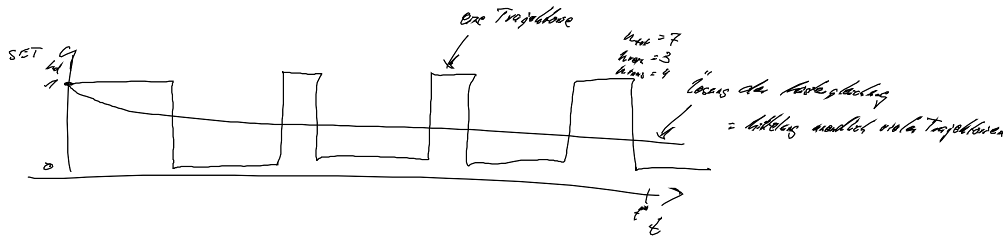
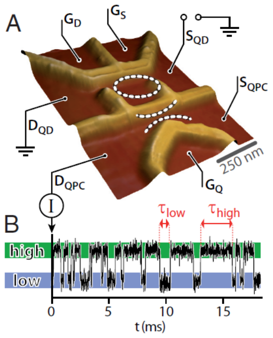
Wdh

- $Z^{BAS} = \begin{pmatrix} Z_{app} & 0 \\ 0 & Z_{coh} \end{pmatrix}$ $\qquad \mathrm{Tr}\{ Z\, \hat{O} \} = 0$





PHAS Flindt et al 2009

$P_n(t)$ = WS für n Sprünge in $[0,t]$
z.B. totale # der Sprünge

Phänomenologie $\quad Z = Z_0 + Z_1$ $\quad$ (Z_0: kein Sprung, Z_1: beschreibt Sprung)

Ersetzung

- $Z(\chi) = Z_0 + Z_1 e^{+i\chi}$ $\qquad$ nur Sprünge von Typ 1
- $Z(\chi,\xi) = Z_{00} + Z_1 \cdot e^{i\chi} + Z_2 \cdot e^{i\xi}$ $\qquad$ 1 & 2
- $Z(\chi) = Z_0 + Z_+ e^{+i\chi} + Z_- e^{-i\chi}$ $\qquad$ Netto-Transfer

MGF
$$M(\chi,t) = \mathrm{Tr}\{ e^{Z(\chi)\cdot t} \rho_0 \} = \sum_n P_n(t) \cdot e^{in\chi}$$
$$\langle n^k \rangle = (-i\partial_\chi)^k M(\chi,t)\big|_{\chi=0}$$
$$P_n(t) = \frac{1}{2\pi} \int_{-\pi}^{\pi} M(\chi,t)\, e^{-in\chi}\, d\chi$$

CGF
$$C(\chi,t) = \ln M(\chi,t) \xrightarrow{t\to\infty} \lambda_{dom}(\chi)\cdot t \qquad \lim_{\chi\to 0} \lambda_{dom}(\chi) \overset{!}{=} 0$$

Bsp $\quad$ SET $\quad$ Netto-Sprünge über die linke Barriere
$$Z(\chi) = \begin{pmatrix} -\Gamma_L f_L - \Gamma_R f_R & \Gamma_L(1-f_L) e^{-i\chi} + \Gamma_R(1-f_R) \\ \Gamma_L f_L \cdot e^{+i\chi} + \Gamma_R f_R & -[\Gamma_L(1-f_L) + \Gamma_R(1-f_R)] \end{pmatrix}$$
$$\rightsquigarrow P_n(t) = \frac{1}{2\pi} \int_{-\pi}^{+\pi} e^{C(\chi,t) - in\chi}\, d\chi$$
ist aus Kumulanten rekonstruierbar

$$\langle\langle n \rangle\rangle = \langle n \rangle$$
$$\langle\langle n^2 \rangle\rangle = \langle n^2 \rangle - \langle n \rangle^2$$

3.1.5. Stromformel

$$\frac{d}{dt}\rho(\chi,t) = Z(\chi)\rho(\chi,t) \rightsquigarrow \rho(\chi,t) = e^{Z(\chi)\cdot t}\rho_0 \qquad \text{verallg. DM}$$
$$M(\chi,t) = \mathrm{Tr}\{ e^{Z(\chi)\cdot t} \rho_0 \} \rightsquigarrow \langle n \rangle = (-i\partial_\chi) M(\chi,t)\big|_{\chi=0}$$
$$I_M = \frac{d}{dt}\langle n \rangle = (-i\partial_\chi)\, \mathrm{Tr}\{ Z(\chi) \cdot e^{Z(\chi)\cdot t} \rho_0 \}\big|_{\chi=0}$$
Tr spur-erhaltend
$$= -i\, \mathrm{Tr}\{ Z'(0)\, e^{Z(0)\cdot t} \rho_0 \} - i\, \mathrm{Tr}\{ Z(0) \left(\partial_\chi e^{Z(\chi)\cdot t}\right)\big|_{\chi=0} \rho_0 \}$$
$$\boxed{I_M = -i\, \mathrm{Tr}\{ Z'(0)\, \rho(t) \}} \qquad \bar{I}_M = -i\, \mathrm{Tr}\{ Z'(0)\, \bar{\rho} \}$$

$\mathcal{L}(0)\,\bar\rho = 0$

falls Dynamik ergodisch (hat ein SS)

3.1.6. Beispiel SET

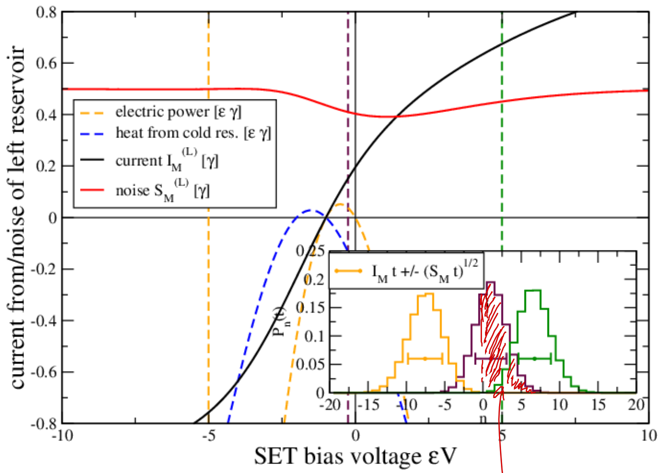
einfacher: $\left.\begin{array}{l}\mu_L \to +\infty \\ \mu_R \to -\infty\end{array}\right\}\begin{array}{l} f_L \to 1 \\ f_R \to 0\end{array}$

$$\mathcal{L}^{\infty}(\chi) = \begin{pmatrix} -\Gamma_L & +\Gamma_R \\ +\Gamma_L e^{+i\chi} & -\Gamma_R \end{pmatrix} \rightsquigarrow \lambda_{\rm dom}(\chi) = -\frac{1}{2}(\Gamma_L+\Gamma_R) + \frac{1}{2}\sqrt{(\Gamma_L-\Gamma_R)^2 + 4 e^{i\chi}\Gamma_L\Gamma_R}$$

$$\frac{d}{dt}\langle\langle n^k\rangle\rangle = (-i\partial_\chi)^k \lambda_{\rm dom}(\chi)\Big|_{\chi=0}$$

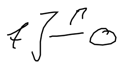
Limes langer Zeiten

$$\frac{d}{dt}\langle\langle n\rangle\rangle = \frac{\Gamma_L\Gamma_R}{\Gamma_L+\Gamma_R}$$



Maschine funktioniert

totale Anzahl der Sprünge nur beim SRL

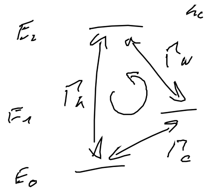


$$\mathcal{L}(\chi) = \Gamma\begin{pmatrix} -f & (1-f)\cdot e^{+i\chi} \\ +f\cdot e^{+i\chi} & -(1-f)\end{pmatrix}$$

$$\langle n\rangle = 2\Gamma\cdot t\, f(1-f) \leq \frac{\Gamma\cdot t}{2}$$

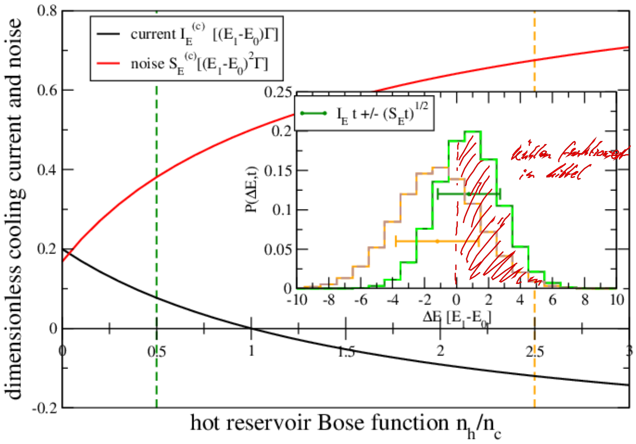
3.1.7 3Level-Kühlschrank/Kältemaschine

$n_c > n_h$



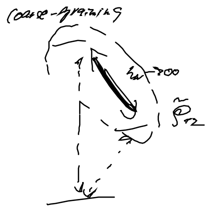
$$\mathrm{vec}(\rho) = \begin{pmatrix}\rho_{00}\\ \rho_{11} \\ \rho_{22}\end{pmatrix}$$

$$\mathcal{L}(\chi) = \begin{pmatrix} -\Gamma_h\cdot n_h - \Gamma_c\cdot n_c & \Gamma_c(1+n_c)\cdot e^{-i\chi} & \Gamma_h(1+n_h) \\ \Gamma_c\cdot n_c\cdot e^{+i\chi} & -\Gamma_w\cdot n_w - \Gamma_c(1+n_c) & \Gamma_w(1+n_w) \\ \Gamma_h\cdot n_h & \Gamma_w n_w & -\Gamma_h(1+n_h) - \Gamma_w(1+n_w)\end{pmatrix}$$



$$I_E^{(c)} = (E_1 - E_0) \cdot I_M^{(c)}$$

kann man $Z_3(z)$ vereinfachen : $n_w \to \infty$



$$\tilde{\rho}_{12} \equiv \rho_{11} + \rho_{22} \qquad \dot{\tilde{\rho}}_{12} = \dot{\rho}_{11} + \dot{\rho}_{22}$$

$$\dot{\rho} = Z(z)\,\rho$$

→ einsetzen :

$$\dot{\rho}_{00} = -[\Gamma_c \cdot n_c + \Gamma_h \cdot n_h] + \left[\Gamma_c (1+n_c) e^{-iz} \frac{\rho_{11}}{\tilde{\rho}_{12}} + \Gamma_h (1+n_h) \frac{\rho_{22}}{\tilde{\rho}_{12}}\right] \tilde{\rho}_{12}$$

$$\dot{\tilde{\rho}}_{12} = +[\Gamma_c \cdot n_c e^{+iz} + \Gamma_h \cdot n_h]\rho_{00} - \left[\Gamma_c (1+n_c) \frac{\rho_{11}}{\tilde{\rho}_{12}} + \Gamma_h (1+n_h) \frac{\rho_{22}}{\tilde{\rho}_{12}}\right] \cdot \tilde{\rho}_{12}$$

red. "Ratengleichung" Nicht-Markovsch

kond. WS für ZS ① falls ⑫ $= P_{1|12}$ $\qquad$ $P_{2|12}$

$$n_w = \frac{1}{e^{\beta_w (E_2 - E_1)} - 1}$$

$$\lim_{n_w \to \infty} \frac{\rho_{11}}{\tilde{\rho}_{12}} \to \frac{1}{2} \qquad \lim_{n_w \to \infty} \frac{\rho_{22}}{\tilde{\rho}_{12}} \Rightarrow \frac{1}{2}$$

→ Reduktion auf Markov'sche 2×2 Matrix

3.2. Energie-aufgelöste Zählstatistik

Bsp: → 3 Zählfelder

$$Z_3(\chi, \xi, \sigma) = \begin{pmatrix} [\ldots] & \Gamma_c (1+n_c) e^{-i\chi} & \Gamma_h (1+n_h) e^{-i\xi} \\ \Gamma_c \cdot n_c \cdot e^{+i\chi} & [\ldots] & \Gamma_w (1+n_w) \cdot e^{-i\sigma} \\ \Gamma_h \cdot n_h \cdot e^{+i\xi} & \Gamma_w \cdot n_w \cdot e^{+i\sigma} & [\ldots] \end{pmatrix}$$

$P_{n_c,n_h,n_w}(t) \quad \rightsquigarrow \quad \Delta E = n_c\cdot(E_1-E_0) + n_h\,(E_2-E_0) + n_w\,(E_2-E_1)$

das geht einfacher $\rightsquigarrow$ ZF für Energie

$$\mathcal{L}_3(\chi) = \begin{pmatrix} [\ldots] & \Gamma_c(1+n_c)\,e^{+i\chi(E_1-E_0)} & \Gamma_h(1+n_h)\,e^{+i\chi(E_2-E_0)} \\ \Gamma_c\cdot n_c\,e^{-i\chi(E_1-E_0)} & [\ldots] & \Gamma_w(1+n_w)\,e^{+i\chi(E_2-E_1)} \\ \Gamma_h\cdot n_h\,e^{-i\chi(E_2-E_0)} & \Gamma_w\cdot n_w\cdot e^{-i\chi(E_2-E_1)} & [\ldots] \end{pmatrix}$$

~~Beweis~~ 3.3: Wartezeit vs. FCS für 2 Energien

~~$P_{n_1,n_2}(t)$: WS für Teilchen-Zählung~~ $\leftarrow M(\chi_1,\chi_2,t)$

Ansatz: $P(E,t) = \sum_{n_1 n_2} \underbrace{P_{n_1,n_2}(t)\,\delta(n_1\Delta E_1 + n_2\Delta E_2, E)}_{\text{verschiedene Sprungterme}}$

kein Sprung

$$M(\chi,t) = \sum_E P(E,t)\,e^{+iE\cdot\chi} = \sum_E \sum_{n_1 n_2} \left[\frac{1}{(2\pi)^2}\int_{-\pi}^{+\pi} d\chi_1 \int_{-\pi}^{+\pi} d\chi_2\, M(\chi_1,\chi_2,t)\, e^{-in_1\chi_1 - in_2\chi_2}\right] \times$$

$$\times\, e^{+iE\cdot\chi}\,\delta(n_1\Delta E_1 + n_2\Delta E_2, E)$$

$$= \sum_{n_1 n_2}\left[\left(\frac{1}{2\pi}\right)^2 \int d\chi_1 \int d\chi_2\, M(\chi_1,\chi_2,t)\, e^{-in_1\chi_1 - in_2\chi_2 + i\chi(n_1\Delta E_1 + n_2\Delta E_2)}\right]$$

$$= \int d\chi_1 \int d\chi_2\, \delta(\chi_1 - \chi\cdot\Delta E_1)\,\delta(\chi_2 - \chi\,\Delta E_2)\, M(\chi_1,\chi_2,t)$$

$$= M(\chi\Delta E_1, \chi\Delta E_2)$$

3.3. WZ vs FCS

$N=1 \qquad \mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1$

$P_n(t)$: WS, n Sprünge in $[0,t]$

$W(\tau)$: WS-Dichte für eine WZ τ zwischen 2 Sprüngen

WS für keinen Sprung in $[0,t]$: $\quad P_0(t) = \mathrm{Tr}\{e^{\mathcal{L}_0 t}\rho_0\}$

WS für ein Sprung in $[t, t+dt]$ $\quad W(t)\cdot dt = P_0(t) - P_0(t+dt)$

$\rightsquigarrow W(t) = -\frac{d}{dt}P_0(t) = -\mathrm{Tr}\{\mathcal{L}_0\cdot e^{\mathcal{L}_0 t}\rho_0\}$ $\quad$ WZ-Verteilung zwischen 2 Sprüngen