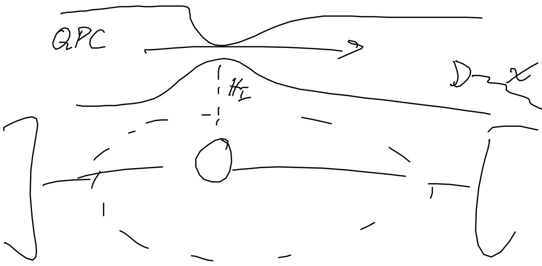
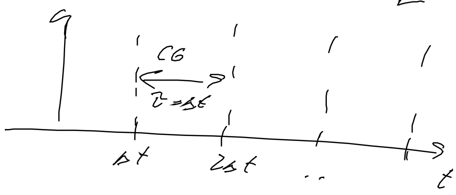
° Wdh



$D \to x \quad H_I = \underbrace{\left(\mathbb{1} - \delta d^\dagger d\right)}_{A} \otimes \sum_{kk'} \left(t_{kk'} \gamma_{kL}^\dagger \gamma_{k'R} + h.c.\right)$

← projektive Messung von $|n\rangle\langle n|$

$n \in \mathbb{Z}$



a.) $\Delta t = \tau \to 0$

• keine Markov-Näherung

• lokale Lindblad Dynamik

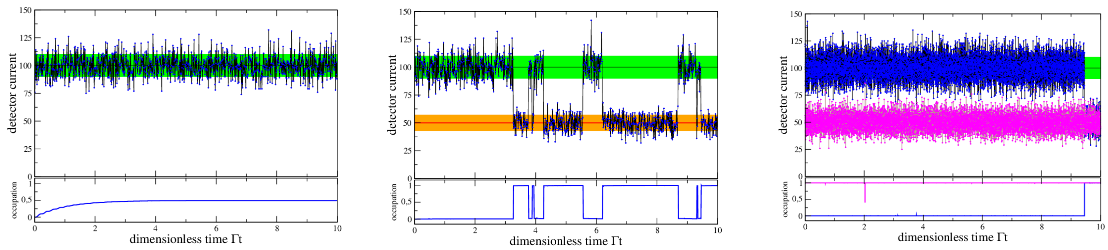
$\mathcal{L}\rho \sim \left[e^{-x} A \rho A - \frac{1}{2}\{A^2, \rho\}\right]$

• für $x \to 0$

$\mathcal{L}\rho \sim \gamma\left[d^\dagger d \rho d d^\dagger + d d^\dagger \rho d^\dagger d\right]$

→ Dämpfung bestimmter Kohärenzen in lok. Basis

TQD:



b.) $\Delta t = \tau \to \infty$ Markov+Säkular-Näherung

$\tilde{A}(t) = \hat{A}_0 + \sum_n \left(\hat{A}_+^n \cdot e^{+i\omega_n t} + \hat{A}_-^n e^{-i\omega_n t}\right)$

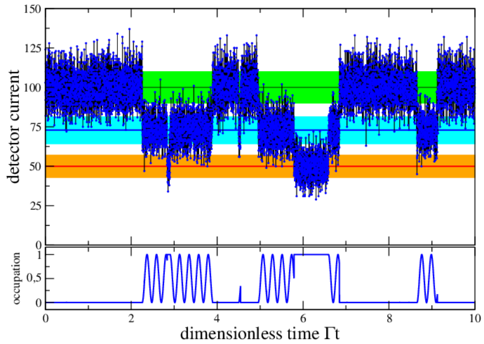
Bohr-Frequenzen

$[A_0, H_S] = 0$

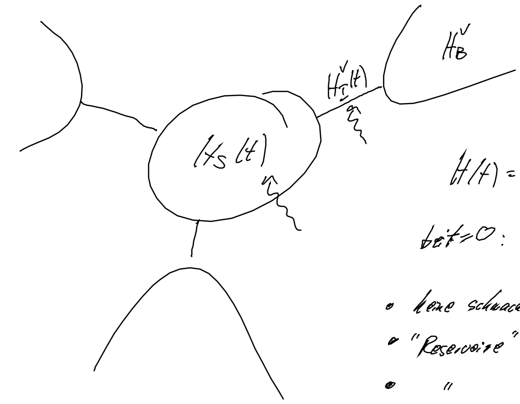
$\gamma(\omega_n) = 0$

$\gamma(0) \neq 0$

Detektor misst I_0 QND-Messung —> FT wird durch die Präsenz eines Det. nicht gestört



7.4. Nicht-perturbative Form der Entropie-Produktion



$$H(t) = H_S(t) + \sum_\nu H_I^\nu(t) + \sum_\nu H_B^\nu$$

bei $t=0$: $\rho(0) = \rho_S(0) \bigotimes_\nu \bar\rho_\nu$ $\bar\rho_\nu = \frac{e^{-\beta_\nu(H_B^\nu - \mu_\nu N_B^\nu)}}{Z_\nu}$

- keine schwache Kopplung
- "Reservoire" können endlich sein
- " können aus GG getrieben werden

Esposito NJP 2010
van den Broeck
Lindenberg

$$\Sigma(t) = -\mathrm{Tr}\{\rho(t)\ln\rho(t)\} = \Sigma(0) = \underbrace{-\mathrm{Tr}_S\{\rho_S(0)\ln\rho_S(0)\}}_{S(0)} - \sum_\nu \mathrm{Tr}_\nu\{\bar\rho_\nu \ln\bar\rho_\nu\}$$

Entropie d. Universums ist konstant

red. DM von System $\rho_S(t) = \mathrm{Tr}_{\{\nu\}}\{\rho(t)\}$ —> $S(t) = -\mathrm{Tr}_S\{\rho_S(t)\ln\rho_S(t)\}$ nicht konst.

Reservoir $\rho_\nu(t) = \mathrm{Tr}_{\{S,\nu'\neq\nu\}}\{\rho(t)\}$

$$S(0) = \Sigma(t) + \sum_\nu \mathrm{Tr}_\nu\{\bar\rho_\nu \ln\bar\rho_\nu\}$$

$$\Delta S(t) = S(t) - S(0)$$

$$= -\mathrm{Tr}_S\{\rho_S(t) \underbrace{\ln \rho_S(t)}_{\text{lok. in } S}\} + \mathrm{Tr}\{\rho(t)\ln\rho(t)\} - \sum_\nu \mathrm{Tr}_\nu\{\bar{\rho}_\nu \ln \bar{\rho}_\nu\}$$

$$= -\mathrm{Tr}\{\rho(t)\ln\rho_S(t)\} + \quad -\,''\,-$$

$$= -\mathrm{Tr}\{\rho(t)\ln[\rho_S(t)\otimes_\nu \bar{\rho}_\nu]\} + \mathrm{Tr}\{\rho(t)\ln\rho(t)\} + \sum_\nu \mathrm{Tr}_\nu\{[\rho_\nu(t) - \bar{\rho}_\nu]\ln\bar{\rho}_\nu\}$$

$$= \underbrace{D\left(\rho(t) \,\|\, \rho_S(t)\otimes_\nu \bar{\rho}_\nu\right)}_{=\Delta_i S \;\geq 0} - \sum_\nu \beta_\nu \underbrace{\mathrm{Tr}_\nu\{[\rho_\nu(t) - \bar{\rho}_\nu][H_B^{(\nu)} - \mu_\nu N_B^{(\nu)}]\}}_{-\Delta Q^{(\nu)}(t)}$$

$$= \Delta_i S(t) + \sum_\nu \beta_\nu \cdot \Delta Q^{(\nu)}(t)$$

Entropie-Produktion — Wärme, welche in $[0,t]$ das Reservoir verlässt

$$\boxed{\Delta_i S(t) = \Delta S(t) - \sum_\nu \beta_\nu \Delta Q^{(\nu)}(t) \geq 0}$$

Änd. der System-Entropie

- $\lim_{t\to\infty} \frac{1}{t}[\dots]$
- System endlich & nehme stat. ZS an

$$\lim_{t\to\infty} \frac{\Delta_i S(t)}{t} = -\sum_\nu \beta_\nu \lim_{t\to\infty} \frac{\langle (H_\nu - \mu_\nu N_\nu)\rangle_0 - \langle (H_\nu - \mu_\nu N_\nu)\rangle_t}{t}$$

falls gilt

$$\lim_{t\to\infty} \frac{d}{dt}\langle H_\nu\rangle_t = -\bar{I}_E^\nu$$

$$\lim_{t\to\infty} \frac{d}{dt}\langle N_\nu\rangle_t = -\bar{I}_M^\nu$$

$$\Rightarrow \boxed{-\sum_\nu \beta_\nu(\bar{I}_E^{(\nu)} - \mu_\nu \bar{I}_M^{(\nu)}) \geq 0}$$

im steady state

- für $t>0$ ist Σ nicht mehr die Summe aus System & Bad-Entropie

$$S_\nu(t) = -\mathrm{Tr}_\nu\{\rho_\nu(t)\ln\rho_\nu(t)\}$$

Korrelations-Entropie

$$\boxed{S_C(t) \equiv \Sigma(t) - S(t) - \sum_\nu S_\nu(t)}$$

$$\boxed{-S_C(t) = D(\rho(t) \,\|\, \rho_S(t)\otimes_\nu \rho_\nu(t))}$$

man zeigt (Skript) $\boxed{\Delta_i S(t) \geq -S_C(t) \geq 0}$

- $\frac{d}{dt}\Delta_i S(t)$ kann i. A. negativ werden

7.4.1. 2 Qbits

$$H = \frac{\omega_1}{2}\sigma_1^z + \underbrace{\frac{\omega_2}{2}\sigma_2^z}_{H_2} + \lambda\,\sigma_1^x\sigma_2^x \qquad \sigma_1^x\sigma_2^x = \sigma^x \otimes \sigma^x$$

$$\rho(0) = \rho_1^0 \otimes \frac{e^{-\beta H_2}}{Z_2} \leftarrow \bar{\rho}_2$$

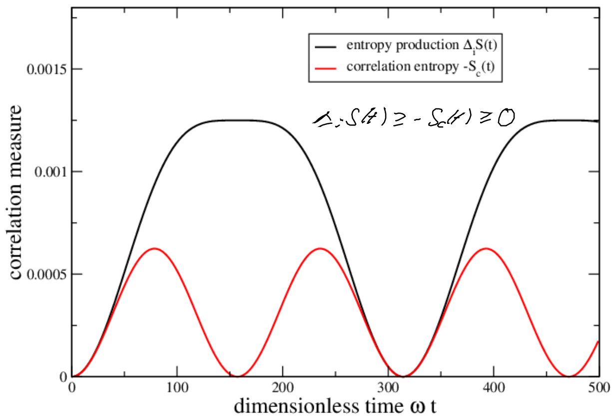
$$\rho(t) = e^{-iHt}\rho(0)\,e^{+iHt}$$

$$\rho_1(t) = \mathrm{Tr}_2\{\rho(t)\} = \frac{1}{2}\left[\mathbb{1} + \vec{h}_1(t)\cdot\vec{\sigma}\right] \qquad \rho_2(t) = \mathrm{Tr}_1\{\rho(t)\} = \frac{1}{2}\left[\mathbb{1} + \vec{h}_2(t)\cdot\vec{\sigma}\right]$$

$$h_1^\alpha = \mathrm{Tr}\{\sigma_1^\alpha\rho(t)\} \qquad h_2^\alpha = \mathrm{Tr}\{\sigma_2^\alpha\rho(t)\}$$

$$\Delta_i S(t) = D\left(\rho(t)\,\|\,\rho_1(t)\otimes\bar{\rho}_2\right)$$

$$-S_c(t) = D\left(\rho(t)\,\|\,\rho_1(t)\otimes\rho_2(t)\right)$$



7.4.2. Pure dephasing

$$H = \Omega\cdot\sigma^z + \lambda\,\sigma^z \otimes \sum_k\left(h_k b_k + h_k^* b_k^\dagger\right) + \sum_k \omega_k b_k^\dagger b_k$$

$$\rightarrow \bullet\ |\rho_{01}(t)| = e^{-f(t)}|\rho_{01}^0| \qquad f(t) = \frac{4}{\hbar}\int \Gamma(\omega)\,\frac{\sin^2(\omega t/2)}{\omega^2}\coth\left(\frac{\beta\omega}{2}\right)d\omega$$

$$\left.\begin{aligned} \bullet\ \Delta E(t) &= \frac{2}{\hbar}\int_0^\infty \frac{\Gamma(\omega)}{\omega}\sin^2\left(\frac{\omega t}{2}\right)d\omega \\ \Delta H(t) &= \frac{2}{\hbar}\int_0^\infty \frac{\Gamma(\omega)}{\omega^2}\sin^2\left(\frac{\omega t}{2}\right)d\omega \end{aligned}\right\} \text{zählt positiv wenn in das Res. abgestrahlt}$$

$$\Delta_i S(t) = S(t) - S(0) + \beta\left[\Delta E(t) - \cancel{\lambda\Delta H(t)}\right] \geq 0$$

7.4.3. Period. Treiben

$$\Delta S(t) = \Delta_i S(t) + \sum_\nu \beta_\nu \Delta Q_\nu(t)$$

Langzeitlimes sei asymptotisch periodisch

für große t^* $\quad S(t^*+T) = S(t^*)$

$$\frac{1}{T}\int_{t^*}^{t^*+T} \frac{d}{dt}[\ldots]$$

• Langzeitströme seien asymptotisch periodisch

Periodenmittel $= \frac{1}{T}\int_t^{t+T}[\ldots]\,dt'$

$$0 = \lim_{t^*\to\infty} \frac{\Delta_i S(t^*+T) - \Delta_i S(t^*)}{T} + \underbrace{\sum_\nu \beta_\nu \left[\langle I_E^{(\nu)}\rangle - \mu_\nu \langle I_M^{(\nu)}\rangle\right]}_{-\langle\sigma\rangle}$$

$$\underbrace{\Delta_i S(t^*+T)}_{\geq 0} = \underbrace{\Delta_i S(t^*)}_{\geq 0} + \langle \sigma\rangle \cdot T$$

$$\Delta_i S(t^*+n\cdot T) = \Delta_i S(t^*) + \langle\sigma\rangle \cdot n \cdot T \qquad n \in \mathbb{Z}^+$$

$$\Rightarrow \quad \langle\sigma\rangle = -\sum_\nu \beta_\nu \left[\langle I_E^{\nu}\rangle - \mu_\nu \langle I_M^{\nu}\rangle\right] \geq 0$$

periodengemittelte Ströme (wenn existent) erfüllen 2. HS