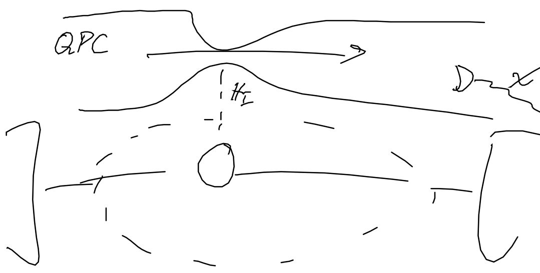
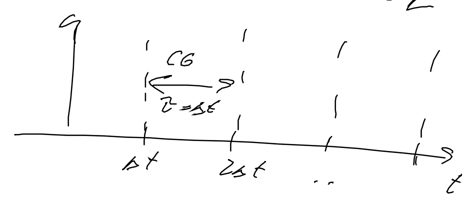
· WdH



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

⇐ projektive Messung von $|n\rangle\langle n|$, $n \in \mathbb{Z}$



a) $\Delta t = \tau \longrightarrow 0$

- keine Markov-Näherung
- lokale Lindblad Dynamik

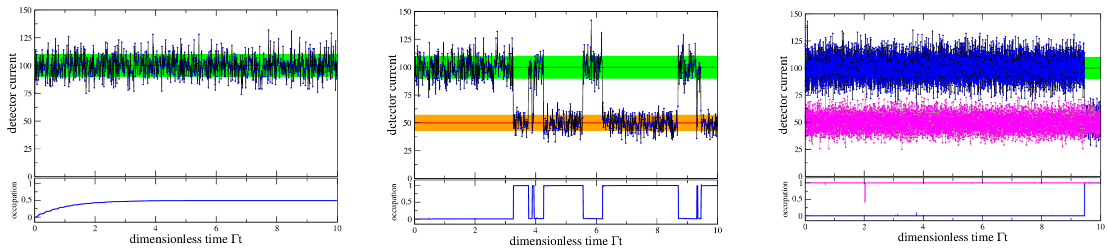
$$\mathcal{L}\rho \propto \left[e^{-i\chi} A \rho A - \frac{1}{2}\{A^2, \rho\}\right]$$

- für $\chi \to 0$

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

→ Dämpfung bestimmter Kohärenzen in lok. Basis

TQD:



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

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

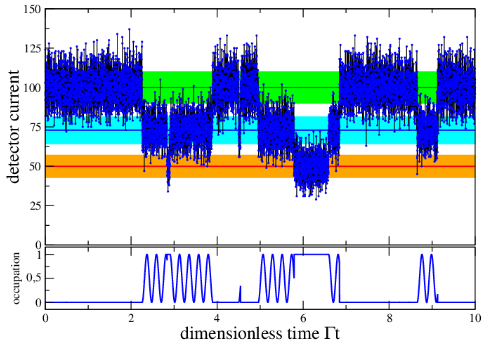
Bohr-Frequenzen

$$[A_0, H_S] = 0$$

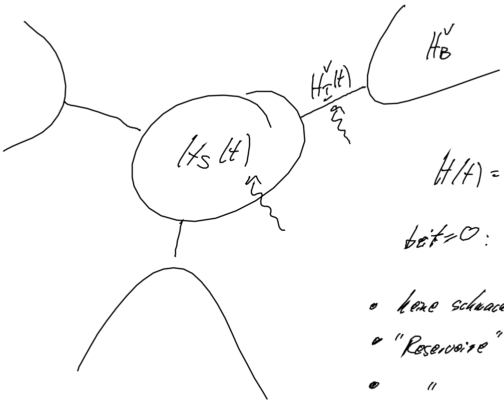
$$\gamma(\omega_n) = 0$$

$$\gamma(0) \neq 0$$

Detektor misst I_0 QND-Messung $\longrightarrow$ 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 $t=0$: $\rho(0) = \rho_S(0) \bigotimes_\nu \bar\rho_\nu$ $\qquad \bar\rho_\nu = \dfrac{e^{-\beta_\nu(H_B^\nu - \mu_\nu N_B^\nu)}}{Z_\nu}$

- 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 $\rho_S(t) = \mathrm{Tr}_{\{\nu\}}\{\rho(t)\}$ $\longrightarrow$ $S(t) = -\mathrm{Tr}_S\{\rho_S(t)\ln\rho_S(t)\}$ nicht konst.

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

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

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

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

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

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

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

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

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

- $\lim_{t\to\infty} \frac{1}{t}[\ldots]$
- 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

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

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

$$\Rightarrow \boxed{-\sum_\nu \beta_\nu\left(\bar I_E^{(\nu)} - \mu_\nu \bar I_M^{(\nu)}\right) \geq 0}$$

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

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

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

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

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

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

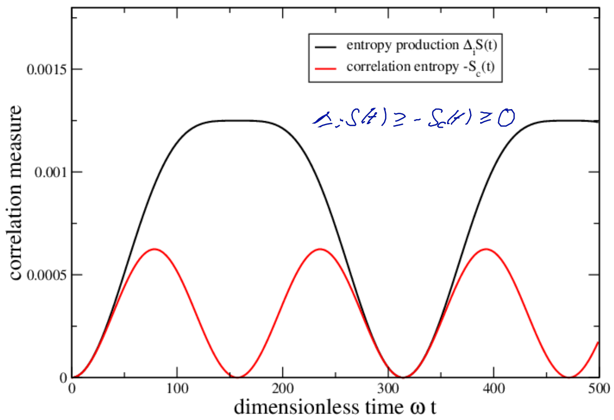
$$\rho(t) = e^{-iHt}\rho(0)\,e^{+iHt}$$

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

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

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

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



7.4.2. Pure dephasing

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

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

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

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

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

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

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

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

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

periodengemittelte Ströme (wenn existent) erfüllen 2. HS