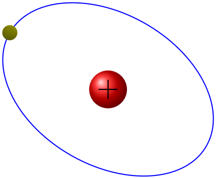
Quantum Dissipation in Periodically Driven Systems

Falk Haßler

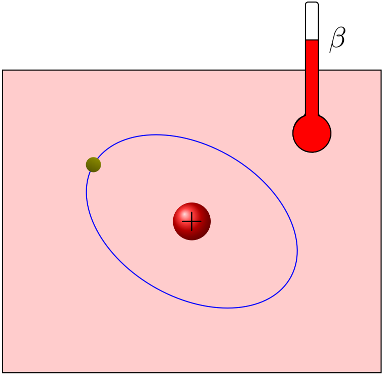
Quantum Dissipation in Periodically Driven Systems

Falk Haßler



Quantum Dissipation in Periodically Driven Systems

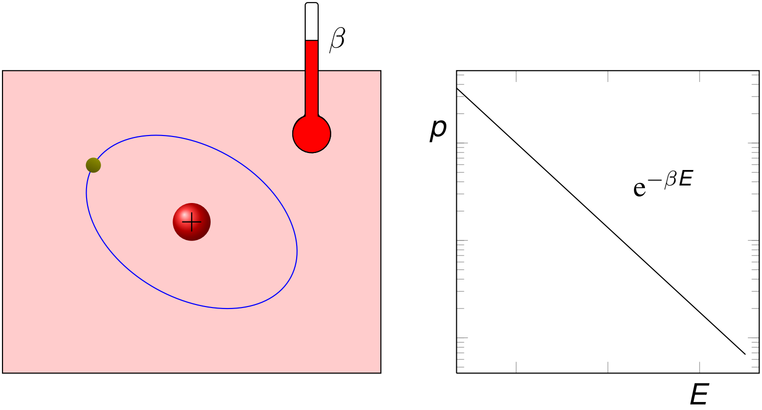
Falk Haßler



TECHNISCHE UNIVERSITÄT DRESDEN
mpipks
cfD DRESDEN
FOR760

Quantum Dissipation in Periodically Driven Systems

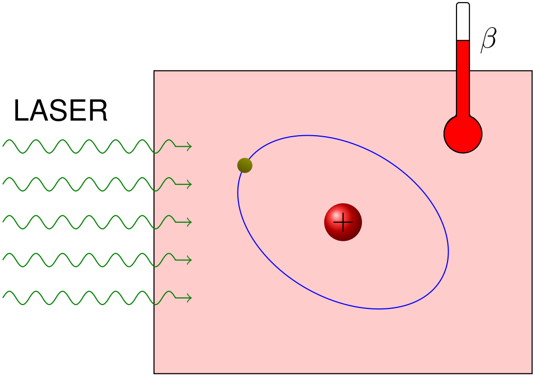
Falk Haßler

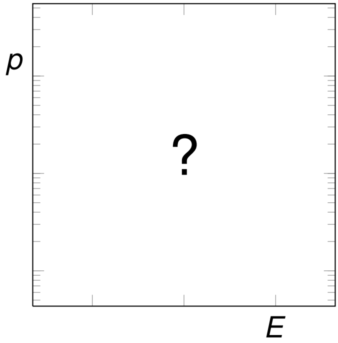


TECHNISCHE UNIVERSITÄT DRESDEN
mpipks
cfD DRESDEN
FOR760

Quantum Dissipation in Periodically Driven Systems

Falk Haßler





TECHNISCHE UNIVERSITÄT DRESDEN

mpipks

CfD DRESDEN

FOR760

Periodically driven systems (e.g. quartic oscillator)

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q, p, t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

- classical mechanics

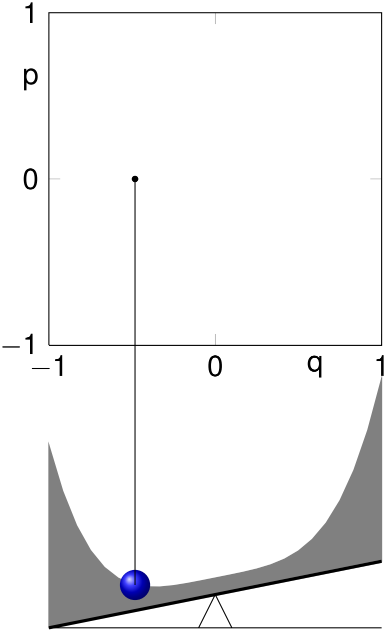
$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

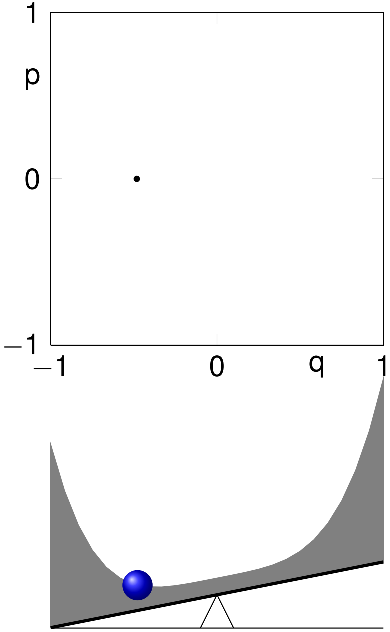


Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

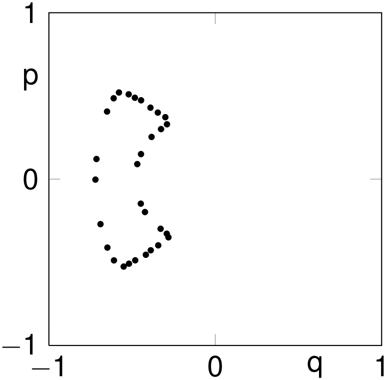
- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$



Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$



- classical mechanics

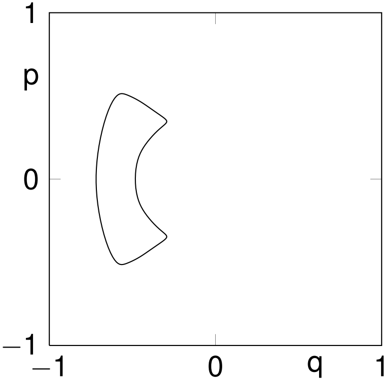
$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

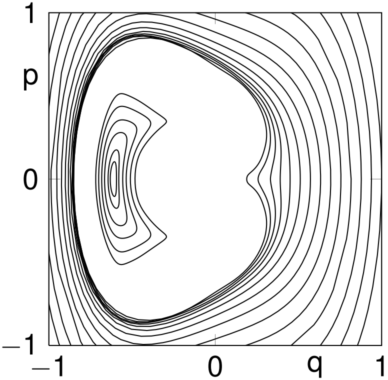
- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$



Periodically driven systems (e.g. quartic oscillator)

$$H(q, p, t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

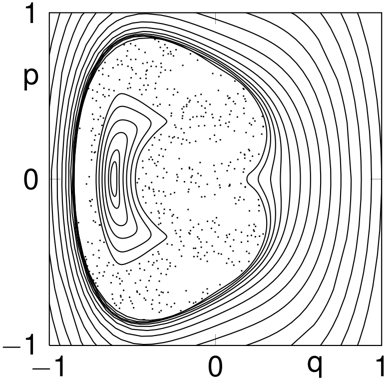


- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

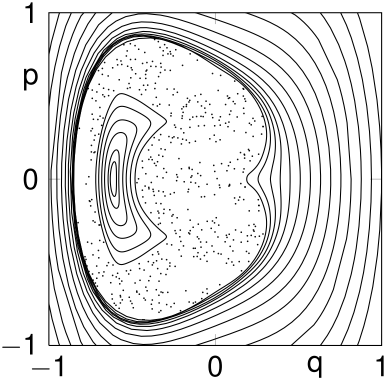


- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$



- classical mechanics

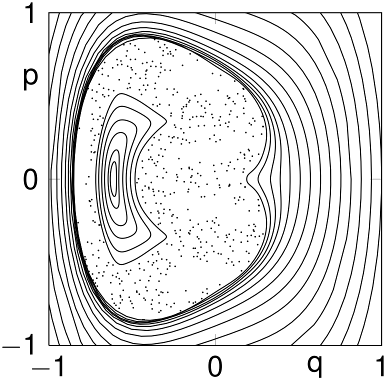
$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

- quantum mechanics

$$\mathrm{i}\hbar \frac{\partial}{\partial t} |\psi(t)\rangle = \hat{H} |\psi(t)\rangle$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$



- classical mechanics

$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

- quantum mechanics

$$\mathrm{i}\hbar \frac{\partial}{\partial t} |\psi(t)\rangle = \hat{H} |\psi(t)\rangle$$

Floquet theorem

$$|\psi_n(t)\rangle = \mathrm{e}^{-\mathrm{i}\epsilon_n t/\hbar} |u_n(t)\rangle$$

Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

- classical mechanics

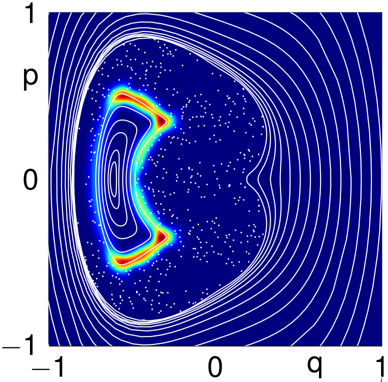
$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

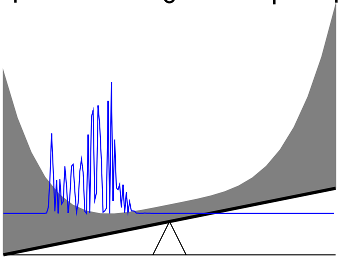
- quantum mechanics

$$\mathrm{i}\hbar \frac{\partial}{\partial t} |\psi(t)\rangle = \hat{H} |\psi(t)\rangle$$

Floquet theorem

$$|\psi_n(t)\rangle = \mathrm{e}^{-\mathrm{i}\epsilon_n t/\hbar} |u_n(t)\rangle$$





Periodically driven systems (e.g. quartic oscillator)

$$H(q,p,t) = \frac{p^2}{2} + q^4 + \kappa q \cos \omega t$$

- classical mechanics

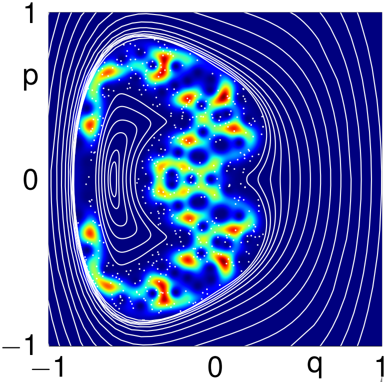
$$\dot{q} = \frac{\partial H}{\partial p} \qquad \dot{p} = -\frac{\partial H}{\partial q}$$

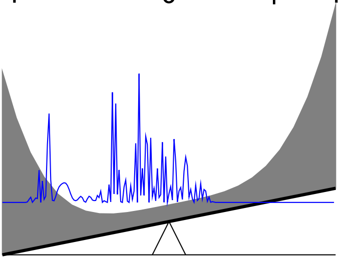
- quantum mechanics

$$\mathrm{i}\hbar \frac{\partial}{\partial t} |\psi(t)\rangle = \hat{H} |\psi(t)\rangle$$

Floquet theorem

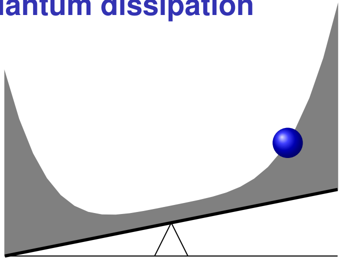
$$|\psi_n(t)\rangle = \mathrm{e}^{-\mathrm{i}\epsilon_n t/\hbar} |u_n(t)\rangle$$





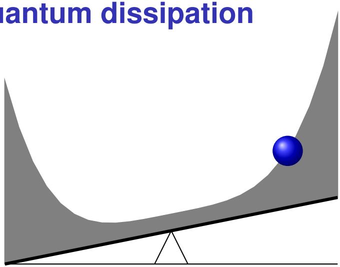
Quantum dissipation

Quantum dissipation

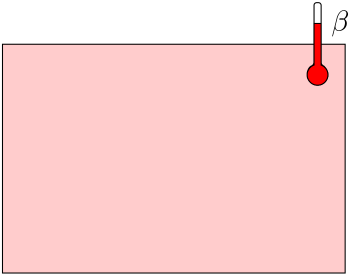


$$\frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t$$

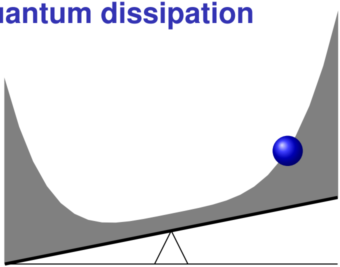
Quantum dissipation



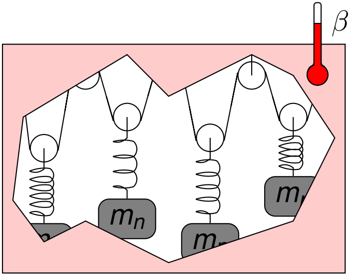
$$\frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa\hat{q}\cos\omega t$$



Quantum dissipation

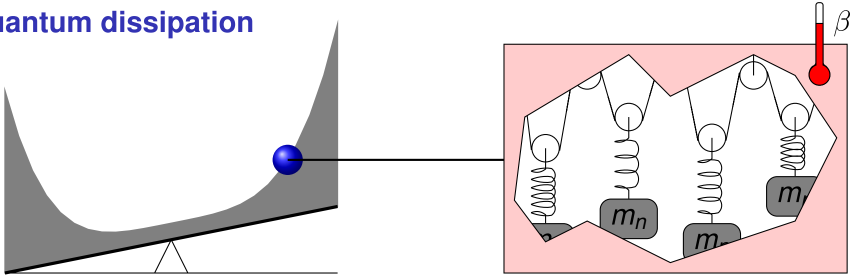


$$\frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa\hat{q}\cos\omega t$$



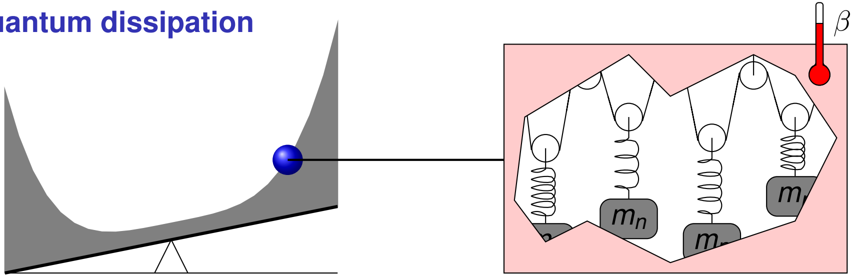
$$\sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n\omega_n^2}{2}\hat{q}_n^2 \right)$$

Quantum dissipation



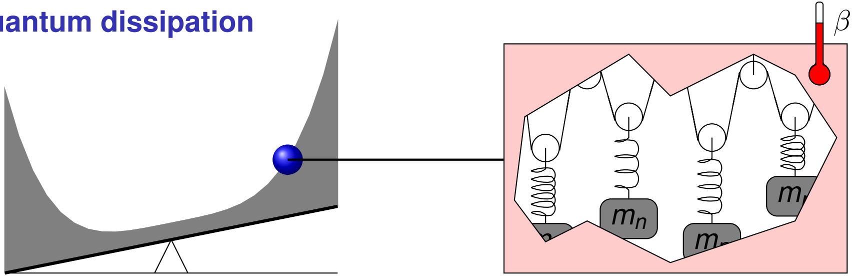
$$\frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t \qquad \hat{A} \sum_n c_n \hat{q}_n \qquad \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

Quantum dissipation



$$\hat{H}_{\mathrm{tot}} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa\hat{q}\cos\omega t \; + \; \hat{A}\sum_n c_n\hat{q}_n + \sum_n\left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n\omega_n^2}{2}\hat{q}_n^2\right)$$

Quantum dissipation

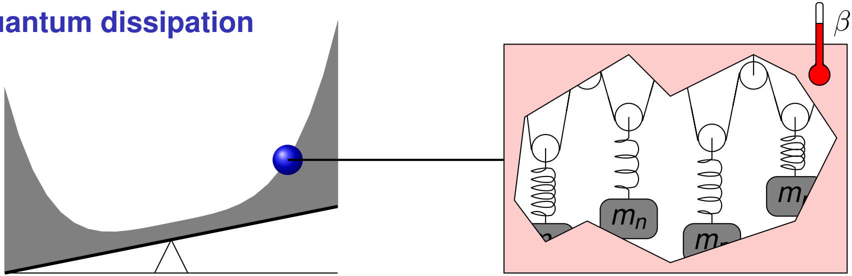


$$\hat{H}_{\text{tot}} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t \; + \hat{A} \sum_n c_n \hat{q}_n + \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

- asymptotic occupation of Floquet states

$$0 = -p_i \sum_j R_{ij} + \sum_j p_j R_{ji}$$

Quantum dissipation



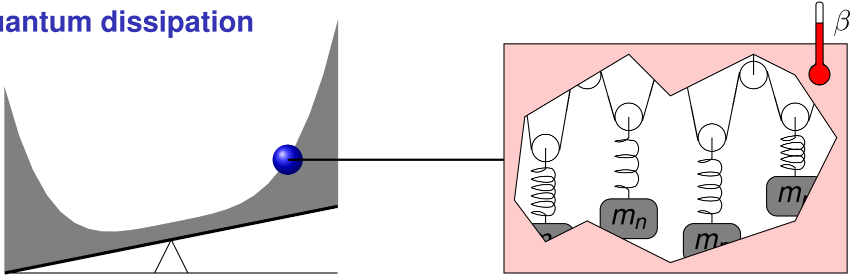
$$\hat{H}_{\mathrm{tot}} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t + \hat{A} \sum_n c_n \hat{q}_n + \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

- asymptotic occupation of Floquet states

$$0 = -p_i \sum_j R_{ij} + \sum_j p_j R_{ji}$$

$$R_{ij} = \frac{\pi}{\hbar} \sum_K \left| A_{ij}(K) \right|^2 g(\epsilon_j - \epsilon_i - K\hbar\omega)$$

Quantum dissipation

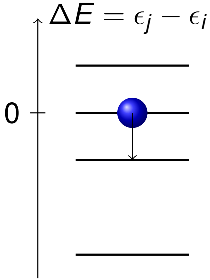


$$\hat{H}_{\text{tot}} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t + \hat{A} \sum_n c_n \hat{q}_n + \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

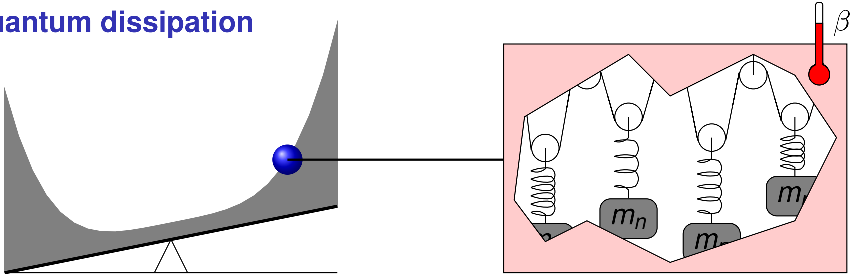
- asymptotic occupation of Floquet states

$$0 = -p_i \sum_j R_{ij} + \sum_j p_j R_{ji}$$

$$R_{ij} = \frac{\pi}{\hbar} \sum_K \left| A_{ij}(K) \right|^2 g(\epsilon_j - \epsilon_i - K\hbar\omega)$$



Quantum dissipation

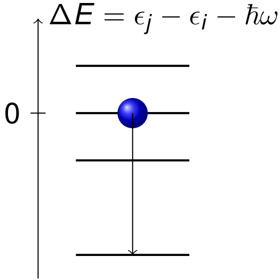


$$\hat{H}_{\text{tot}} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t \; + \hat{A} \sum_n c_n \hat{q}_n + \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

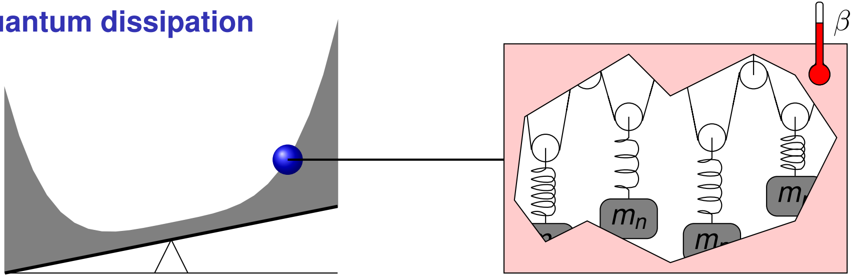
- asymptotic occupation of Floquet states

$$0 = -p_i \sum_j R_{ij} + \sum_j p_j R_{ji}$$

$$R_{ij} = \frac{\pi}{\hbar} \sum_K \left| A_{ij}(K) \right|^2 g(\epsilon_j - \epsilon_i - K\hbar\omega)$$



Quantum dissipation

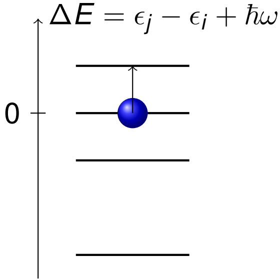


$$\hat{H}_{\rm tot} = \frac{\hat{p}^2}{2} + \hat{q}^4 + \kappa \hat{q} \cos \omega t \; + \hat{A} \sum_n c_n \hat{q}_n + \sum_n \left(\frac{\hat{p}_n^2}{2m_n} + \frac{m_n \omega_n^2}{2} \hat{q}_n^2 \right)$$

- asymptotic occupation of Floquet states

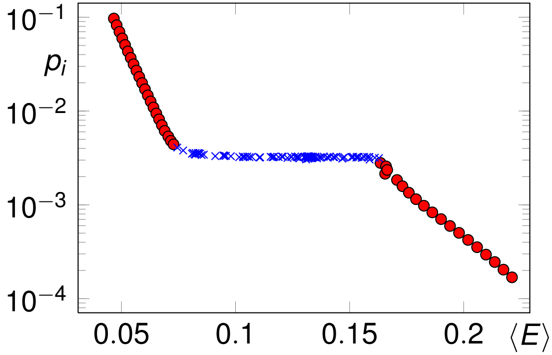
$$0 = -p_i \sum_j R_{ij} + \sum_j p_j R_{ji}$$

$$R_{ij} = \frac{\pi}{\hbar} \sum_K \left| A_{ij}(K) \right|^2 g(\epsilon_j - \epsilon_i - K\hbar\omega)$$

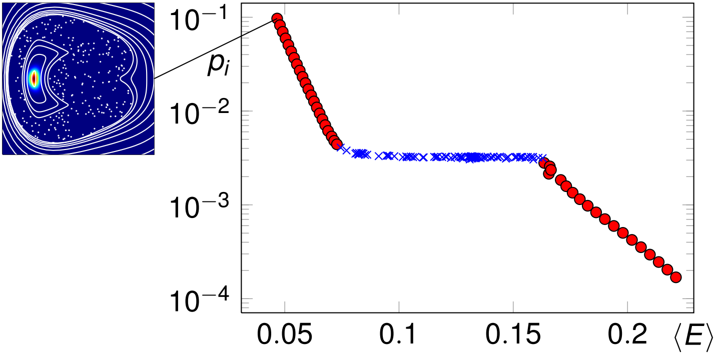


Asymptotic occupation probabilities of the Floquet states

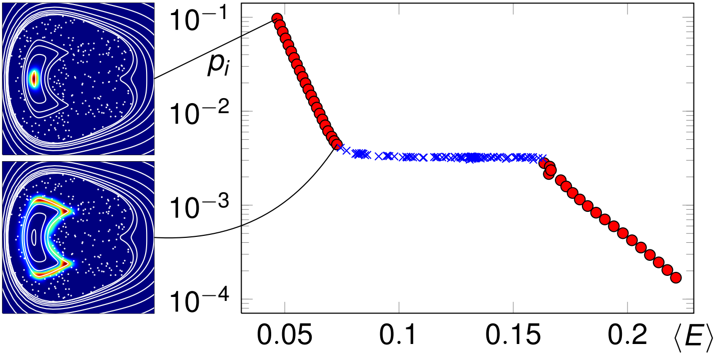
Asymptotic occupation probabilities of the Floquet states



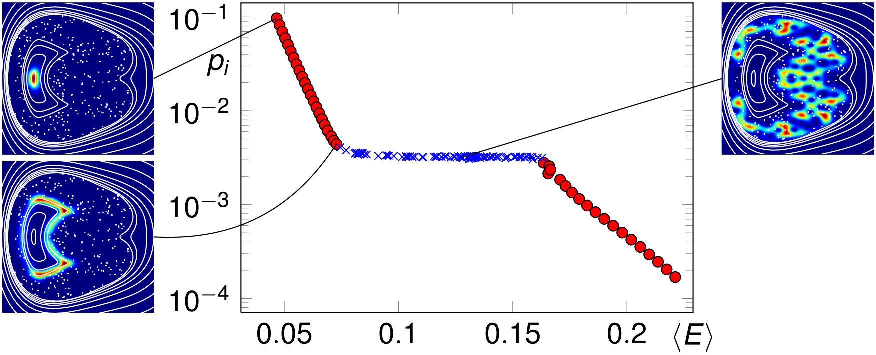
Asymptotic occupation probabilities of the Floquet states



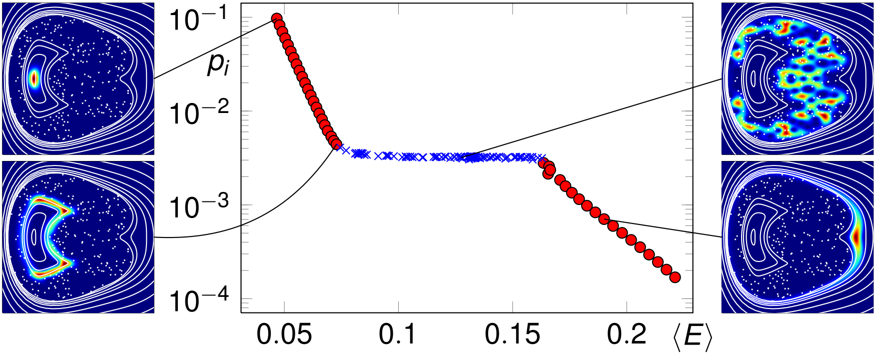
Asymptotic occupation probabilities of the Floquet states



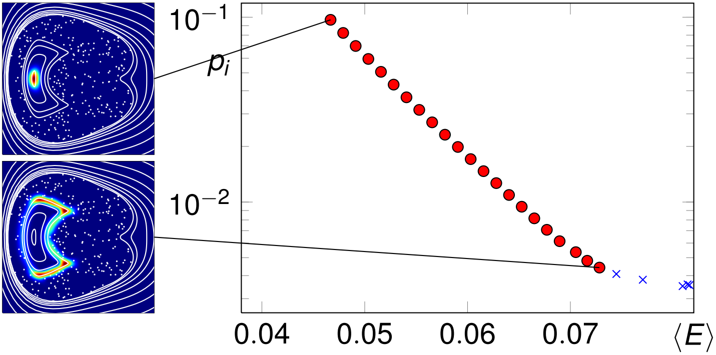
Asymptotic occupation probabilities of the Floquet states



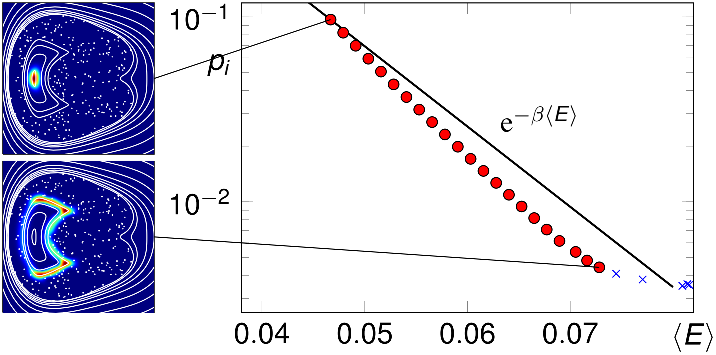
Asymptotic occupation probabilities of the Floquet states



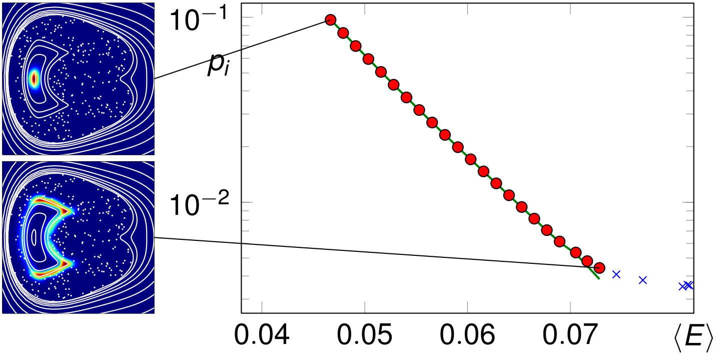
Asymptotic occupation probabilities of the Floquet states



Asymptotic occupation probabilities of the Floquet states



Asymptotic occupation probabilities of the Floquet states



$$R_{ij}^{\mathrm{sc}} = \frac{\gamma^2}{\hbar} \sum_K \left| A_{ij}^{\mathrm{sc}}(K) \right|^2 \left(\frac{2}{\beta\hbar} + \omega_{ij} + \omega K \right) \qquad \omega_{ij} = \omega \nu_{\frac{i+j}{2}} (i - j)$$

$$A_{ij}^{\mathrm{sc}}(K) = \lim_{N\to\infty} \frac{1}{2NT} \int_{-NT}^{NT} \mathrm{d}t\, \tilde{A}_{\frac{i+j}{2}}(t) \exp\left[-\mathrm{i} \left(\omega_{ij} + \omega K \right) t \right]$$