Metastability in the open quantum Ising model

Dominic C. Rose

Physics and Astronomy, University of Nottingham

Katarzyna Macieszczak,
Igor Lesanovsky, Juan P. Garrahan

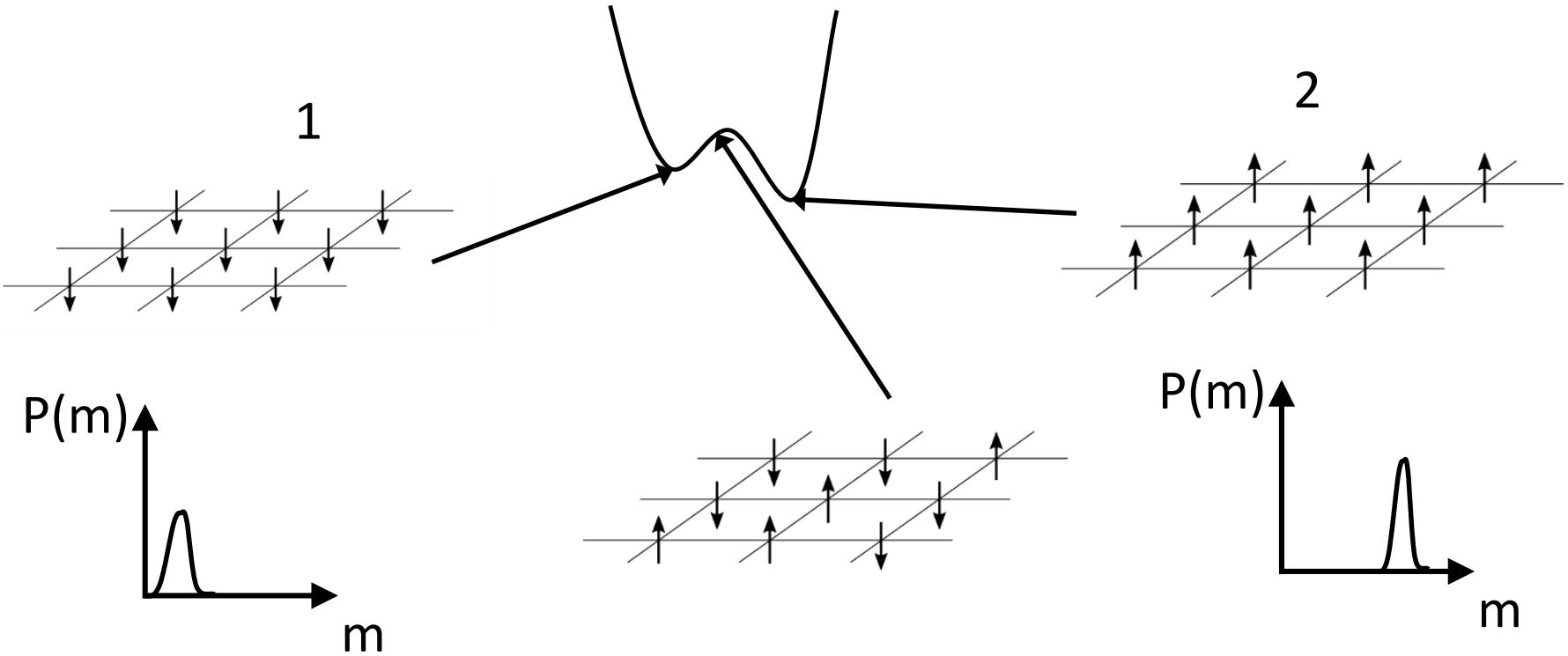
(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Introduction

- What is metastability?
- Open Ising model: what we know
- Open Ising model: metastability study

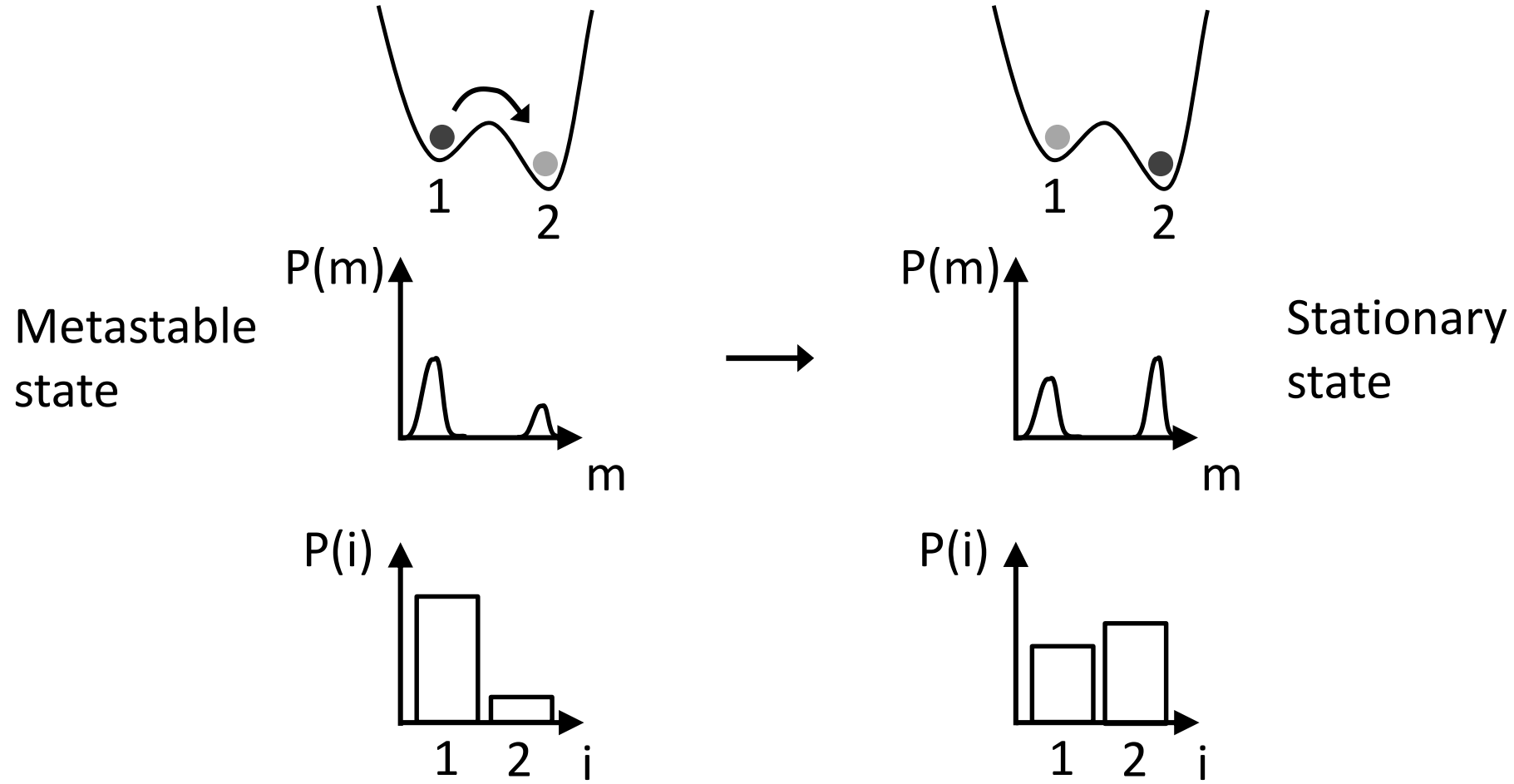
What is metastability?

- Approximate stationarity in evolution



What is metastability?

- Approximate stationarity in evolution

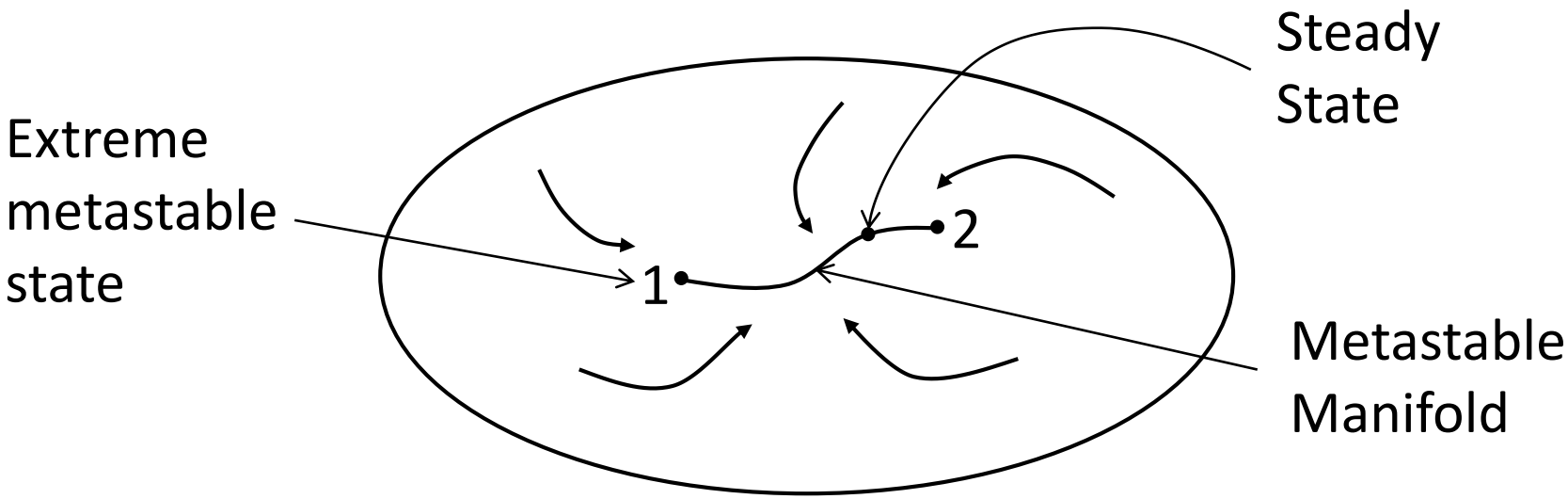


Classical metastability

- Separation of master operator spectrum

$$\frac{dP}{dt} = W(P) \longrightarrow P(t) = \sum_i e^{\lambda_i t} c_i P_i$$

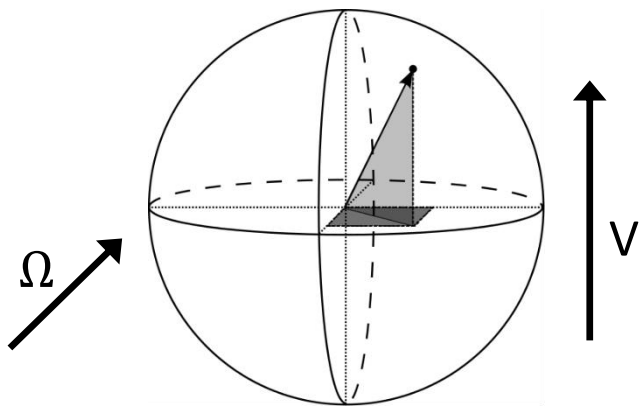
- Reduced dimension at long times

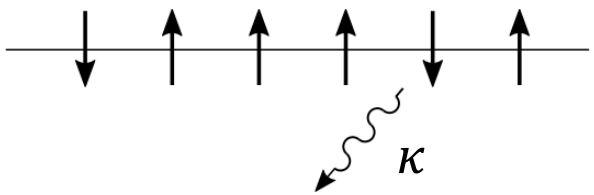


(Gaveau-Schulman 1996)

Open Ising model

- Transverse field, photon emissions





$$H = \Omega \sum_{i=1}^{N} S_x^i + V \sum_{i=1}^{N} S_z^i S_z^{i+1}$$

$$J_i = \sqrt{\kappa}\, S_-^i$$

- Approximate description:

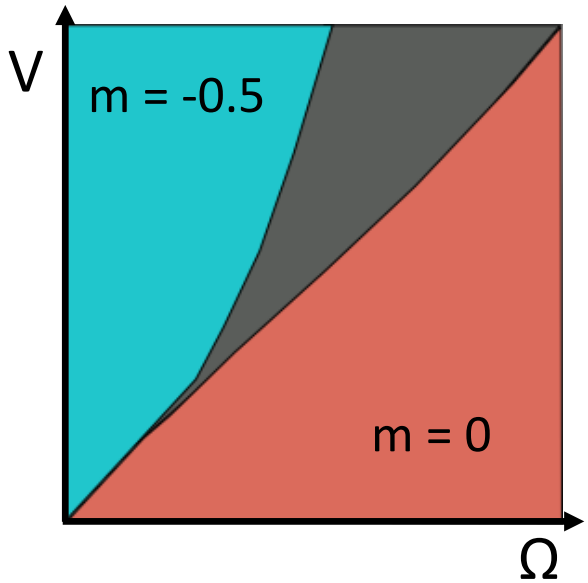
$$\frac{d\rho}{dt} = \mathcal{L}(\rho) = -i[H,\rho] + \sum_{i=1}^{N} \left[J_i \rho J_i^\dagger - \frac{1}{2}\{J_i^\dagger J_i, \rho\} \right]$$

Open Ising model: what we know

- Finite size:

  unique stationary state

(Schirmer-Wang 2010)

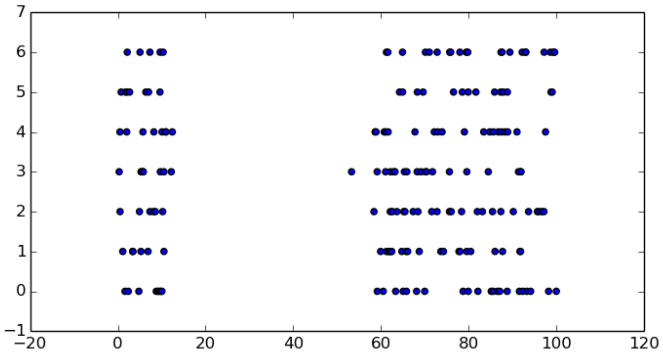


- Mean field bistability

$$m = \frac{1}{N}\sum_{i=1}^{N} S_z^i$$

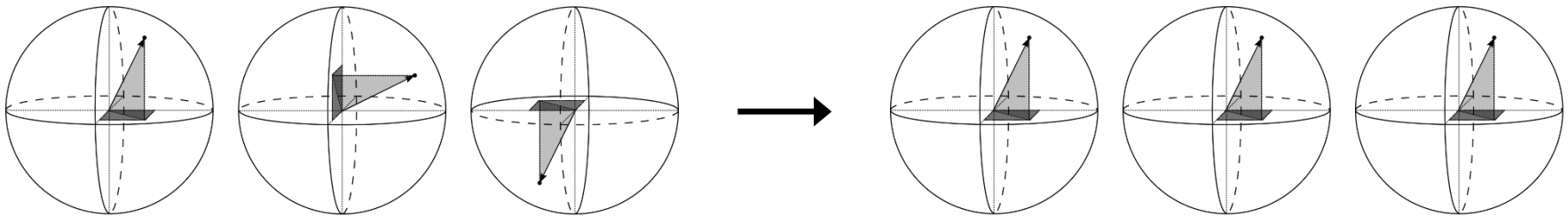
- Intermittent trajectories

(Ates-Olmos-Garrahan-Lesanovsky 2012)



Dynamical mean field

- Approximation: all spins in same state

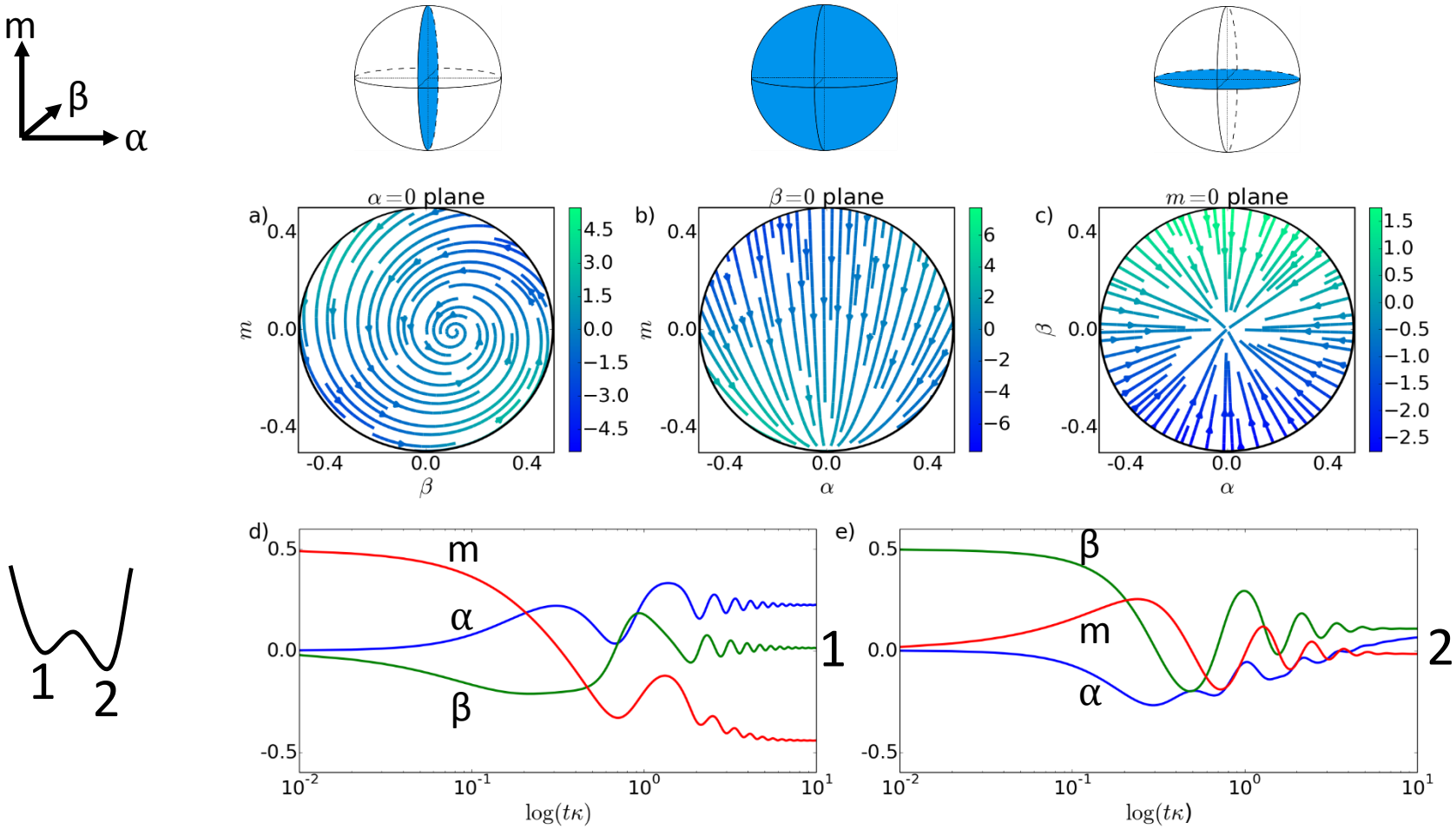


$$\frac{d\rho}{dt} = \mathcal{L}(\rho) \quad \longrightarrow \quad \frac{d\boldsymbol{x}}{dt} = V(\boldsymbol{x})$$

- 3d state space, $\boldsymbol{x} = (\alpha, \beta, m)$

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Dynamical mean field



- Mean field captures short time dynamics

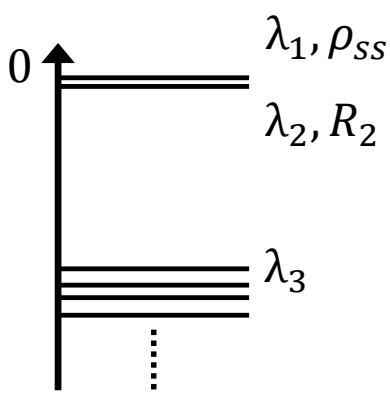
(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Quantum metastability

- 1d case: extreme metastable states (eMS)

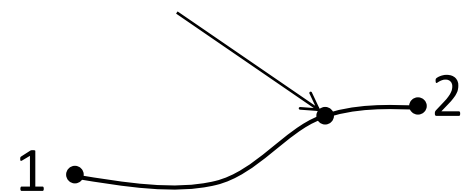
$$\frac{d\rho}{dt} = \mathcal{L}(\rho)$$

$$\downarrow$$

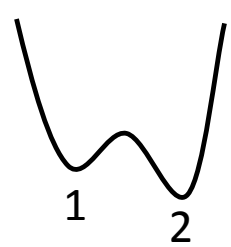


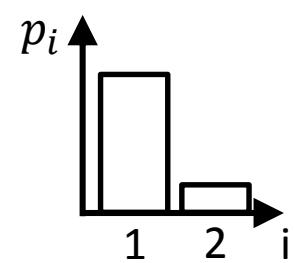
$$\xrightarrow{\left(t \gg -\frac{1}{\lambda_3}\right)}$$

$$\rho(t) \approx \rho_{ss} + e^{t\lambda_2} c_2 R_2$$



$$\rho(t) \approx p_1\rho_1 + p_2\rho_2$$





(Macieszczak-Guţă-Lesanovsky-Garrahan 2016)

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

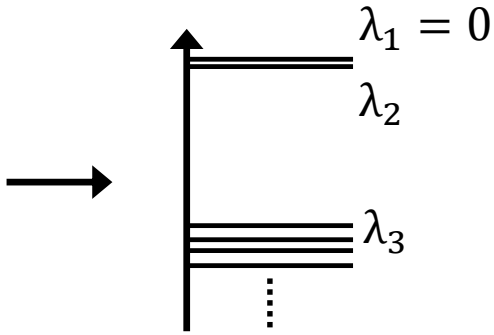
Spectral separation and finite scaling

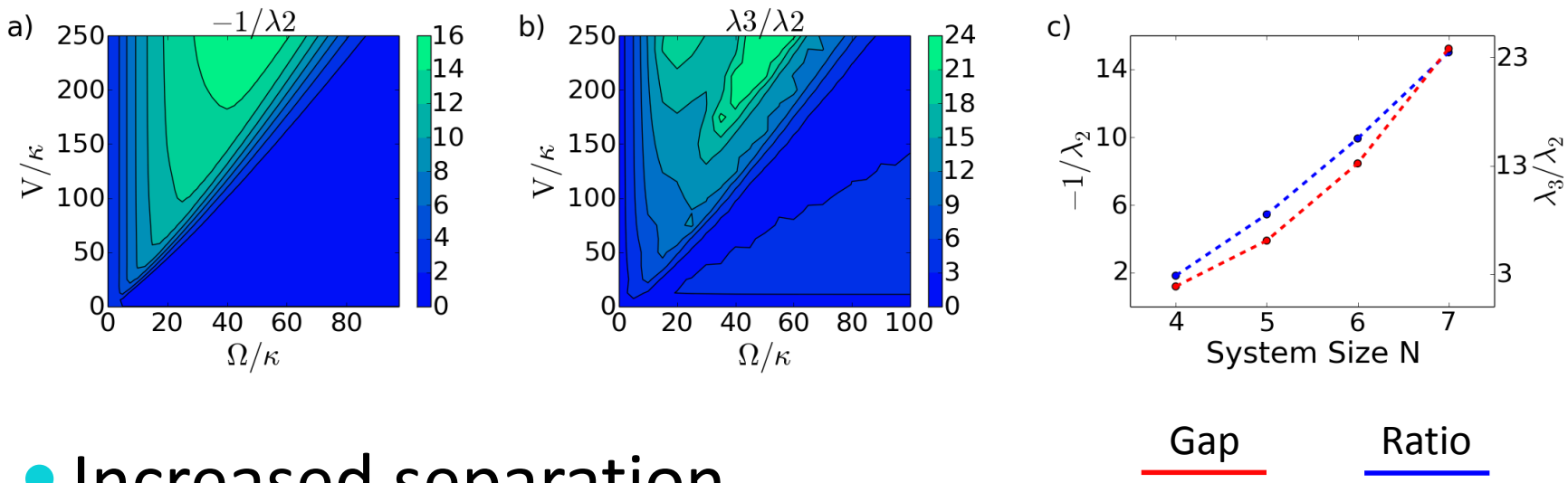
- Spectrum reveals metastable region

$$\frac{d\rho}{dt} = \mathcal{L}(\rho)$$

$$N = 7$$

$$\dim(\mathcal{L}) = 16380$$



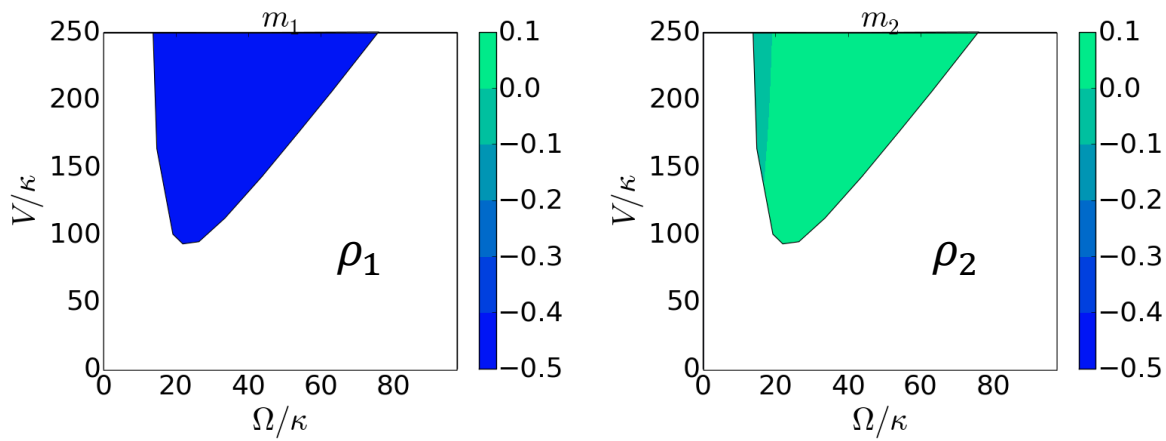


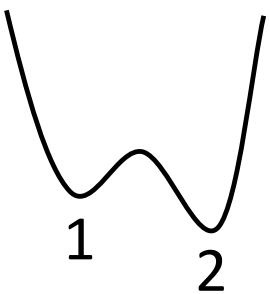
- Increased separation with system size

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Effective model

- Distinct extreme metastable states





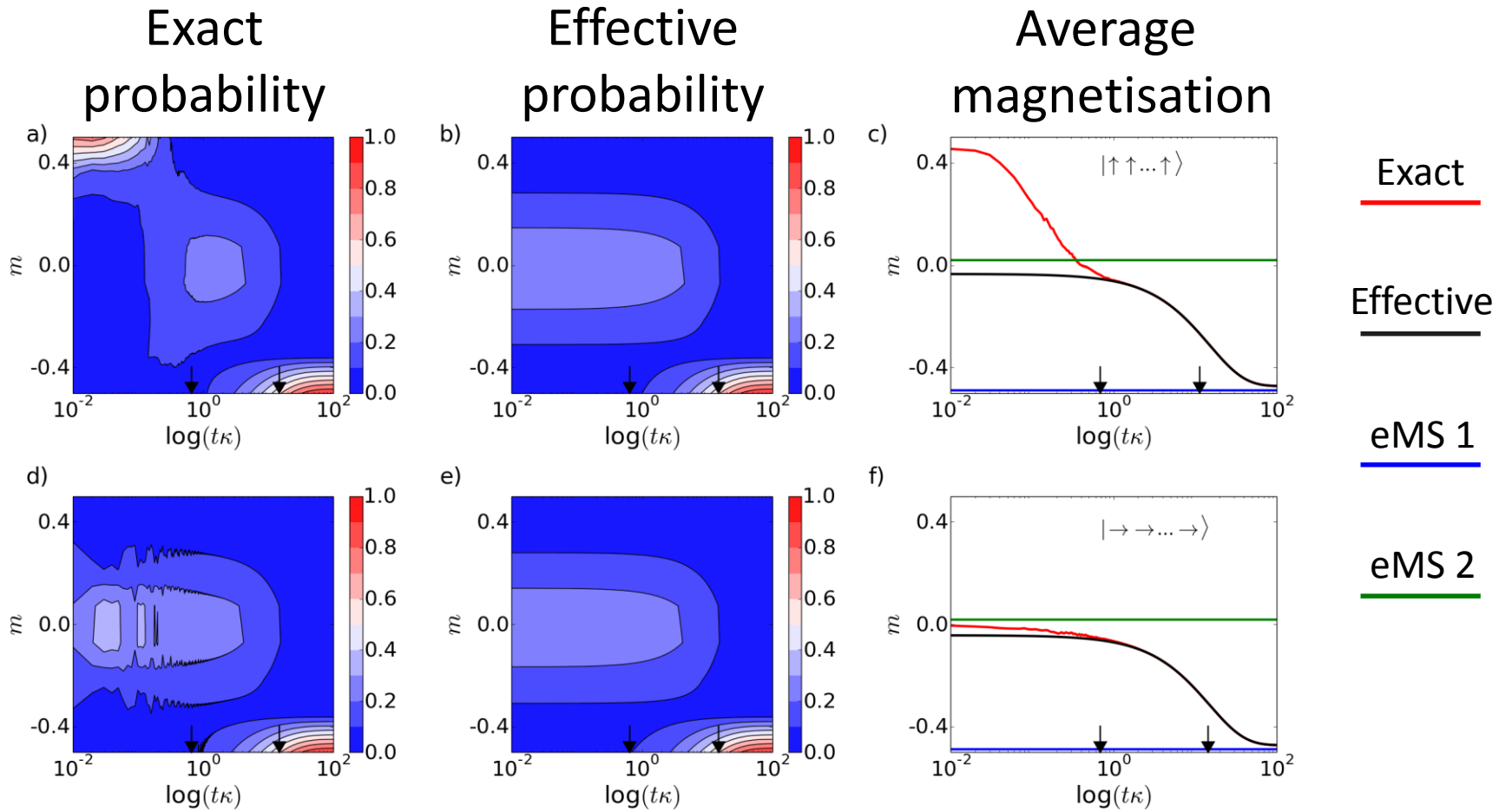
- Effective classical evolution

$$\left(t \gg -\frac{1}{\lambda_3}\right) \qquad \begin{array}{c} \rho(t) \approx p_1\rho_1 + p_2\rho_2 \\ \rho(t) = e^{t\mathcal{L}}(\rho_0) \end{array} \longrightarrow \begin{array}{c} p(0) = (p_1, p_2) \\ p(t) = e^{t\mathcal{L}_{eff}}p(0) \end{array} \qquad (p_1 + p_2 = 1)$$

(Macieszczak-Guţă-Lesanovsky-Garrahan 2016)

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Observables and effective results

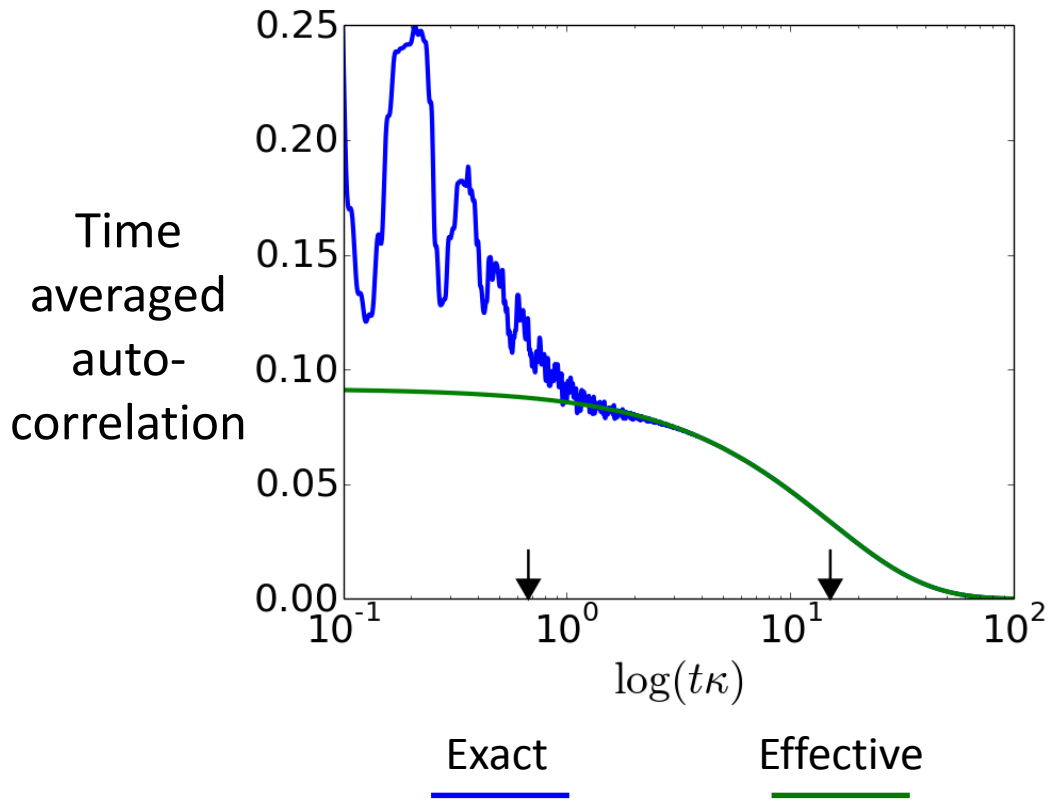


- Metastability in magnetisation

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Steady state correlations

- Observable distinguishes eMS

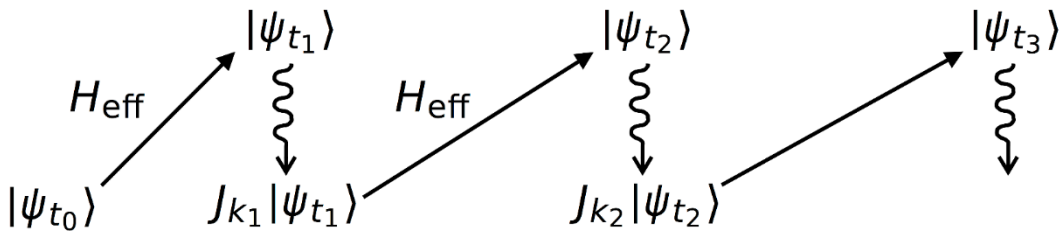


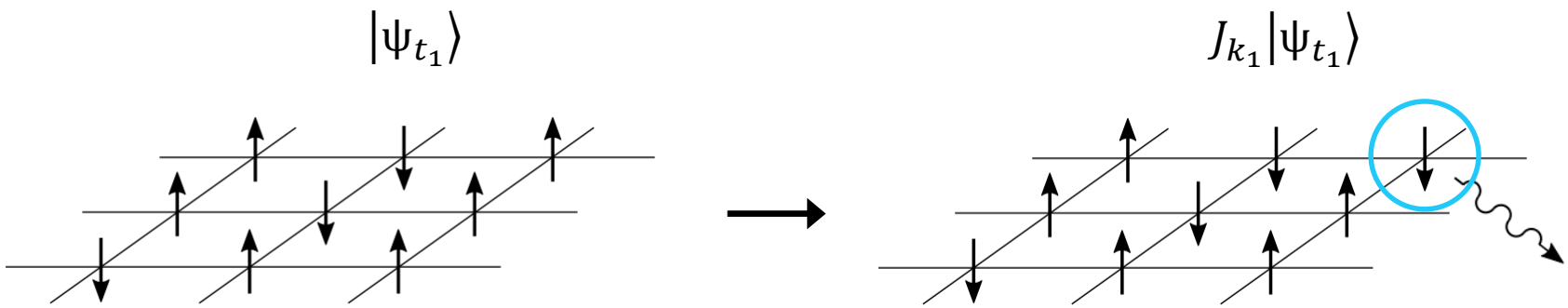
- Metastability in correlations

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Quantum trajectories

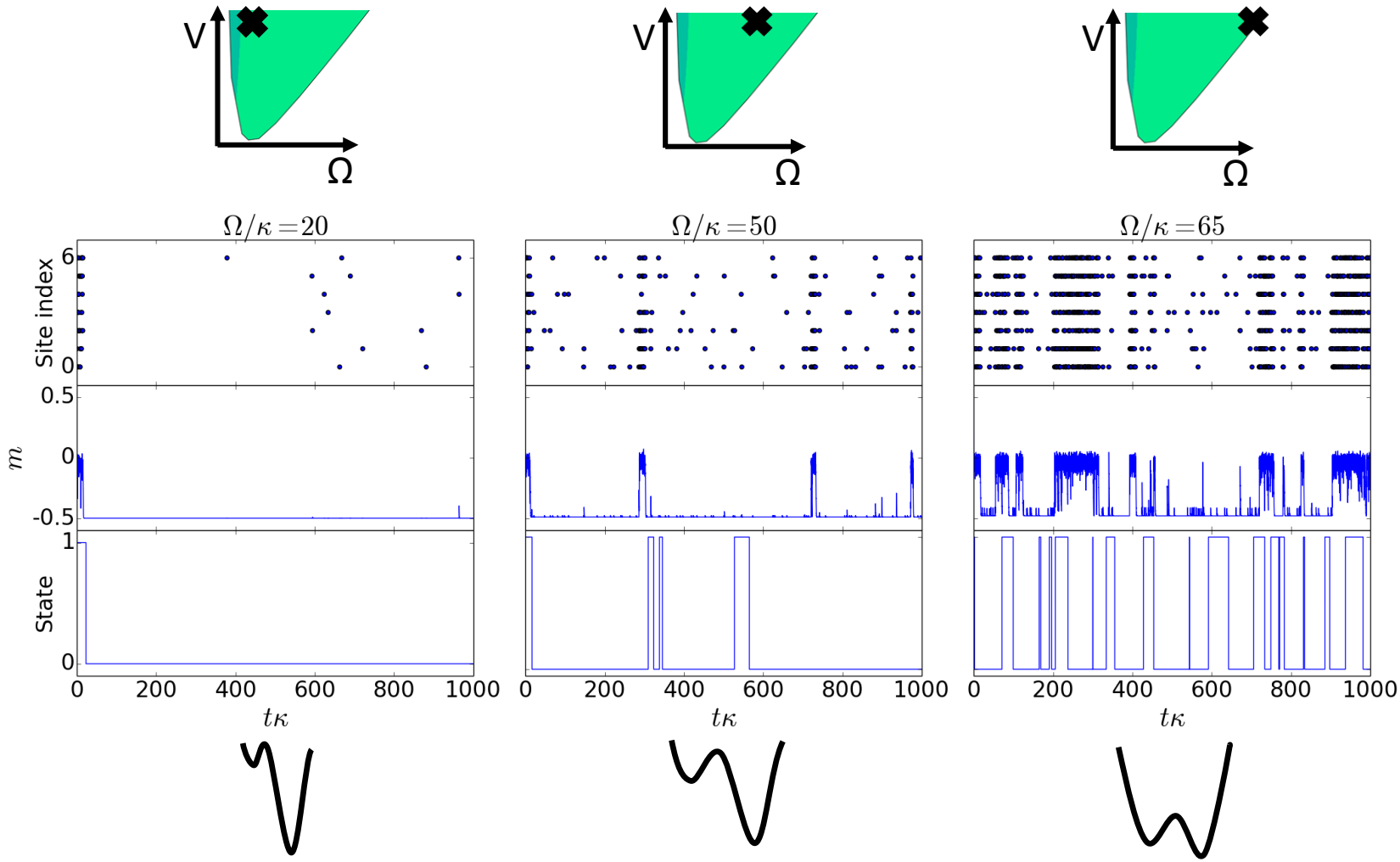
- Pure state simulation: photon emissions





(Gardiner-Zoller, *Quantum Noise*, 2004)

Trajectory intermittence



- Two classical states ⟶ intermittence

(DCR-Macieszczak-Lesanovsky-Garrahan 2016)

Future work

- Quantum glass model: dynamics unrelated to statics

$$H = \Omega \sum_{k=1}^{N} \sigma_x^k f_{k+1}^2(p) \qquad L_k = \sqrt{\kappa}\sigma_k^- f_{k+1}(p)$$

(Lesanovsky-van Horssen-Guta-Garrahan 2013)

- Field theory approach to open Ising model

- Closed system metastability, e.g. quantum non-ergodicity in systems with many-body localisation

Conclusion

- Metastability in the open quantum Ising model
- Mean field evolution trapped in metastable states
- Spectral separation $\longrightarrow$ metastable states + effective evolution
- Physical origin of intermittence