Metastability in open quantum systems

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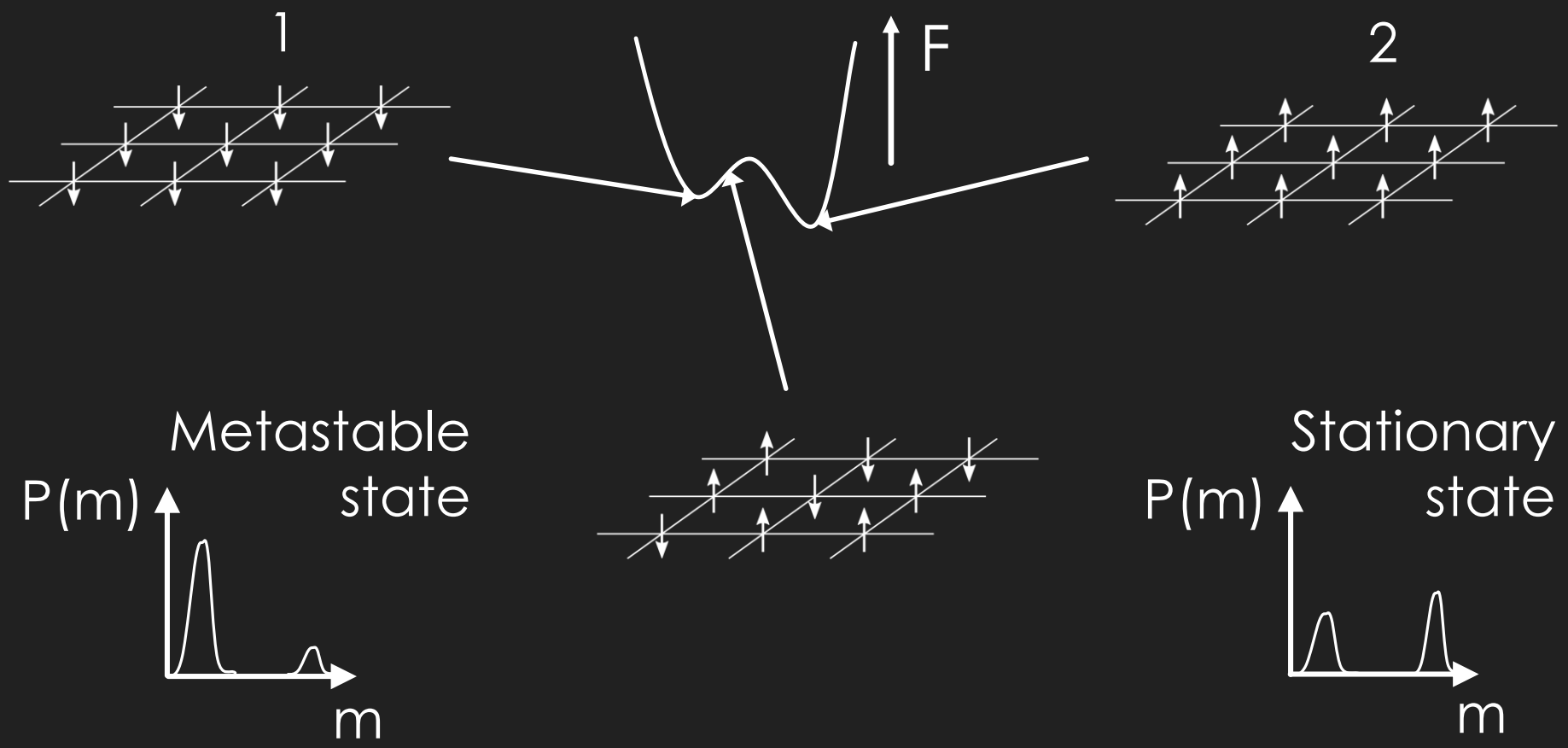
- Metastability in an open quantum Ising model, PRE 94, 052132 (2016)
- Metastability in the open quantum East model, in preparation
- Dynamical nuclear polarization, arXiv:1703.07159

What is metastability?

- Approximate stationarity in evolution



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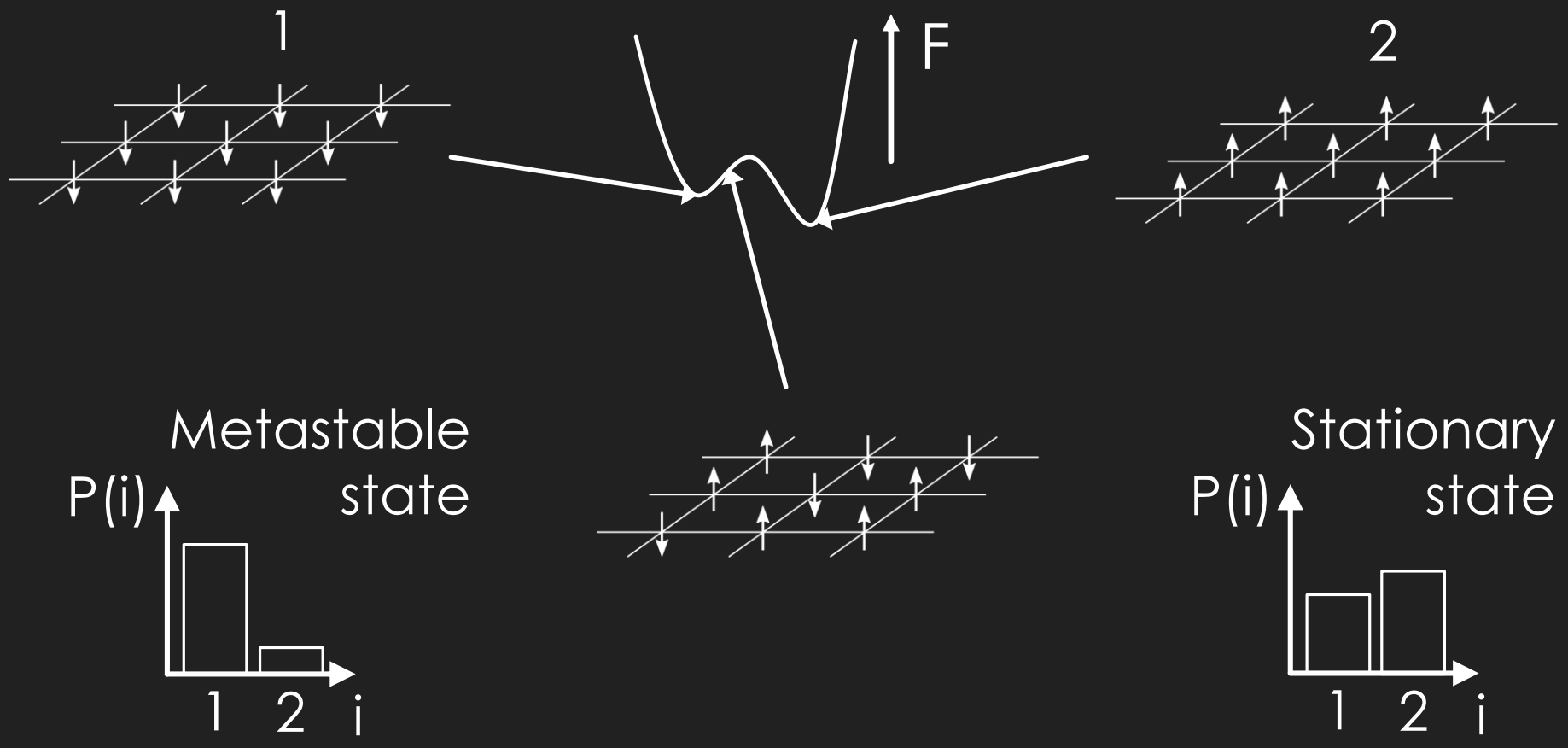
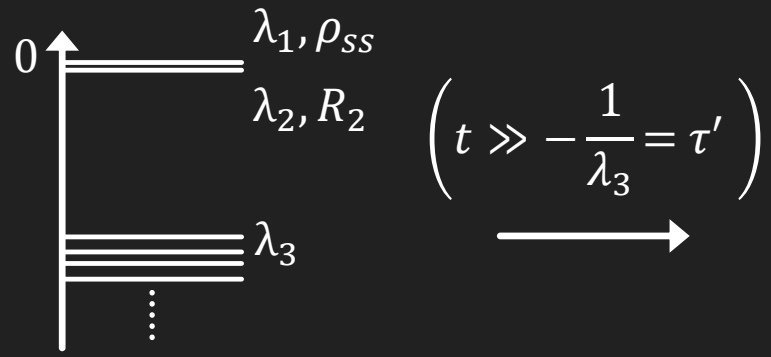


Theory of metastability

- Evolution given by master equation

$$\frac{d\rho}{dt} = \mathcal{L}(\rho) \longrightarrow \rho(t) = \sum_i e^{\lambda_i t} c_i R_i$$

- Reduced dimension from spectral separation



$$\left(t \gg -\frac{1}{\lambda_3} = \tau'\right) \longrightarrow \rho(t) \approx \rho_{ss} + e^{t\lambda_2} c_2 R_2$$

Gaveau-Schulman, J. Mat. Phys. (1996); Macieszczak-Guta-Lesanovsky-Garrahan, PRL (2016)

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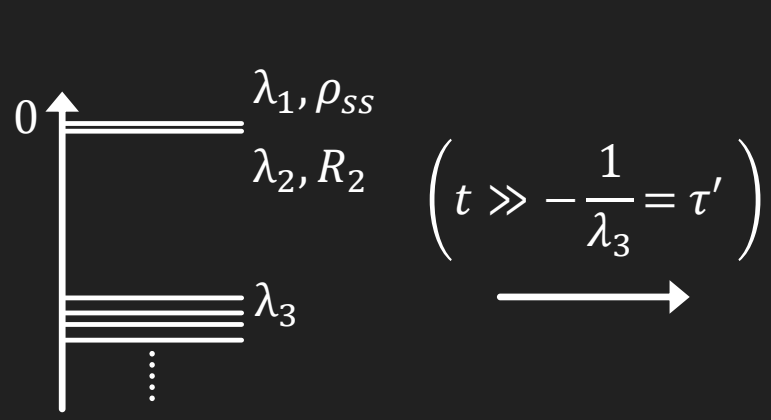

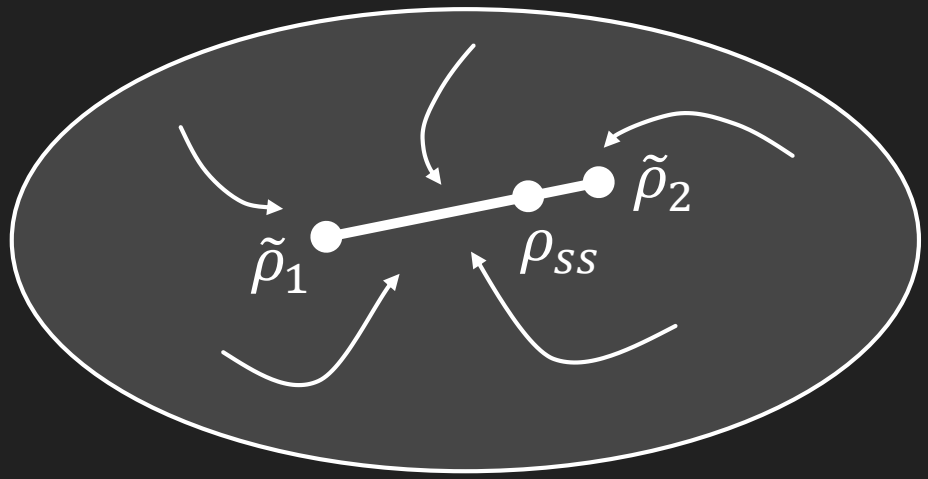

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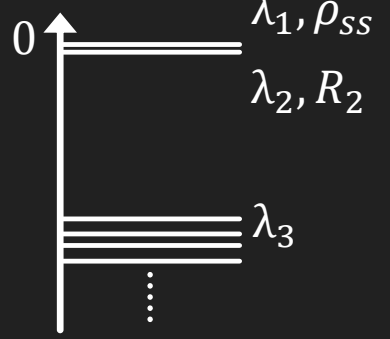
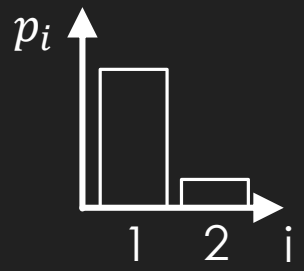


$$\left(t \gg -\frac{1}{\lambda_3} = \tau'\right) \longrightarrow \rho(t) \approx p_1\rho_1 + p_2\rho_2$$



$$\mathcal{L}(\rho) \longrightarrow \mathcal{L}_{\text{eff}} P$$

Gaveau-Schulman, J. Mat. Phys. (1996); Macieszczak-Guta-Lesanovsky-Garrahan, PRL (2016)

Open quantum Ising model

- Described by Lindblad equation

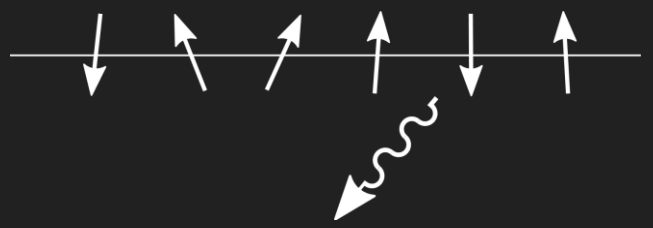
$$\frac{d\rho}{dt} = \mathcal{L}(\rho) = -i[H,\rho] + \sum_{i=1}^{N}\left[J_i \rho J_i^\dagger - \frac{1}{2}\{J_i^\dagger J_i, \rho\}\right]$$

- Coherent evolution: transverse Ising model

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

- Dissipative evolution:

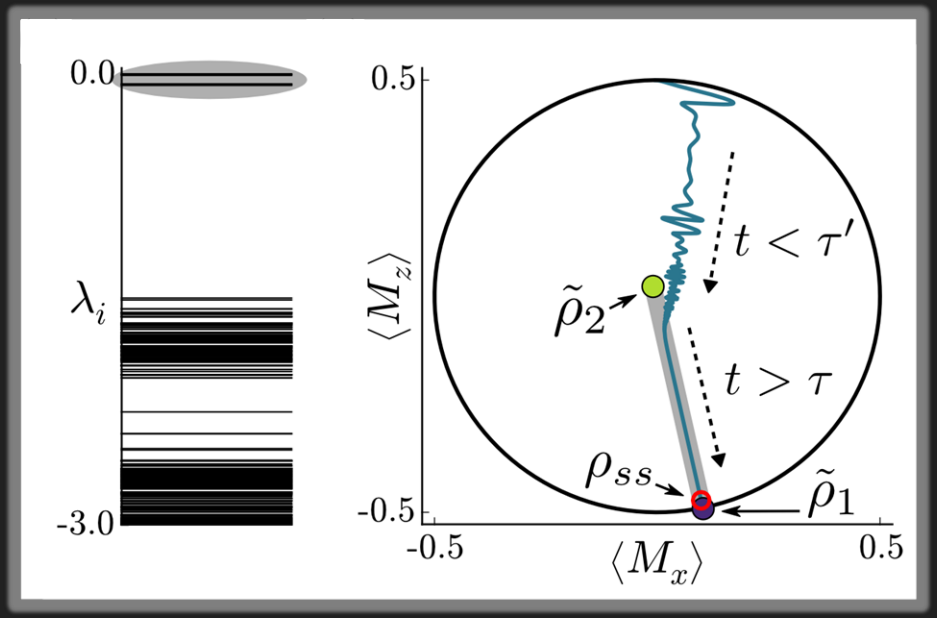
  photon emissions $\quad J_i = \sqrt{\kappa}\, S_-^i$

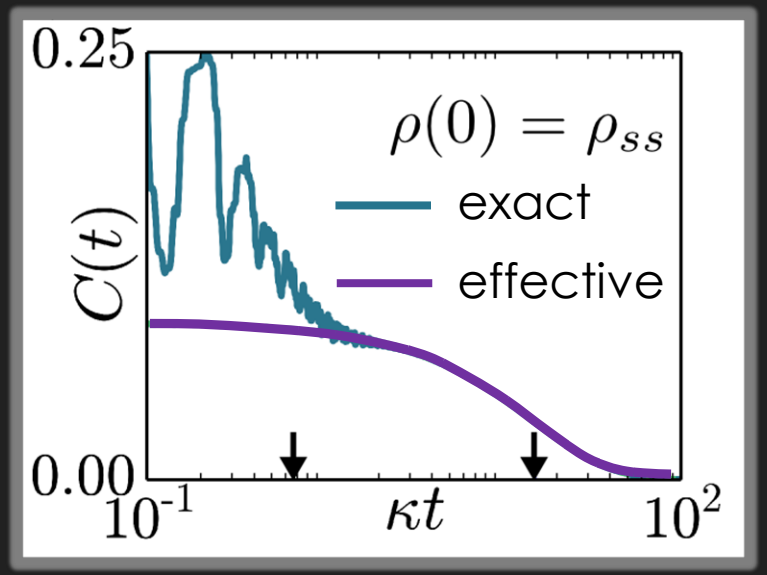


Ates-Olmos-Garrahan-Lesanovsky, PRB (2012)

Open quantum Ising model: metastability

- Separation close to steady state transtion
- Plateau in correlation evolution

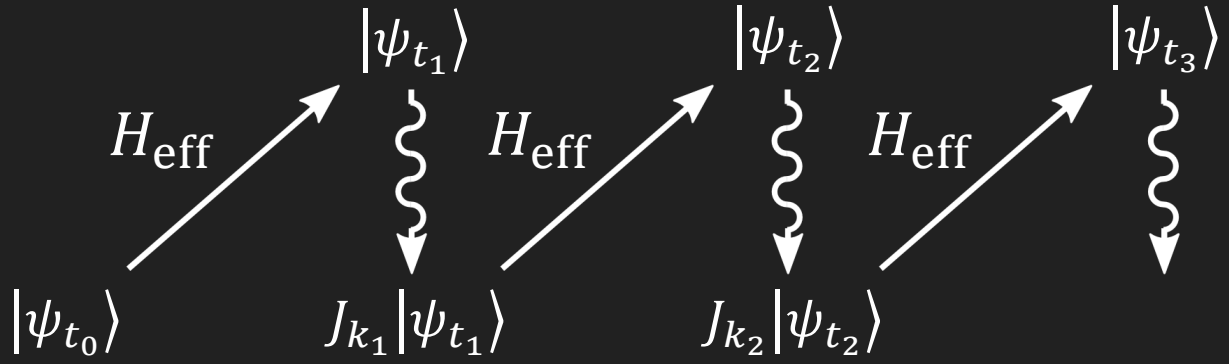


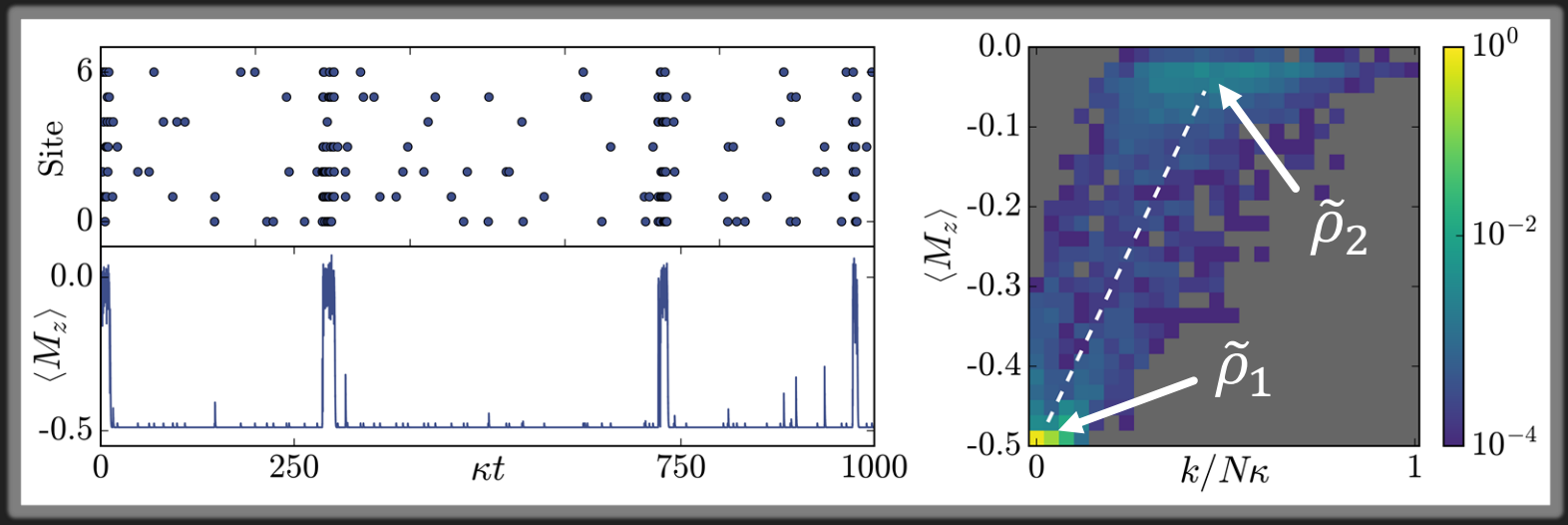


DCR-Macieszczak-Lesanovsky-Garrahan, PRE (2016)

Open quantum Ising model: intermittence

- Alternate approach: trajectories





DCR-Macieszczak-Lesanovsky-Garrahan, PRE (2016)

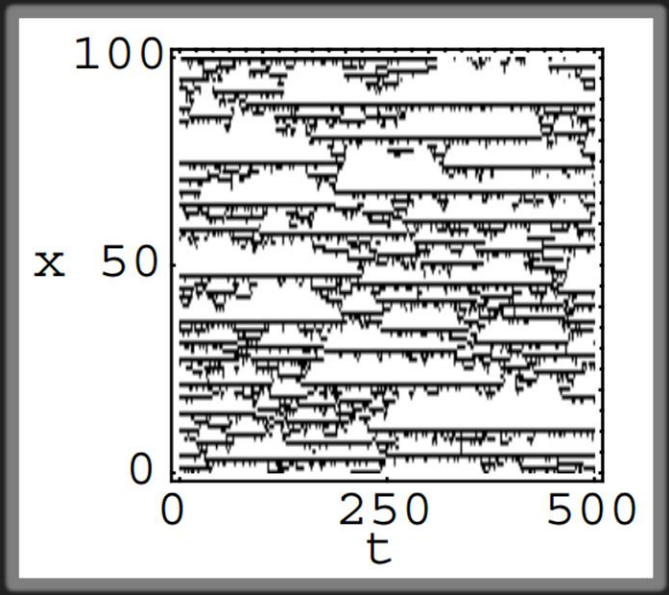
East model

- Constrained spin dynamics

$11 \xrightarrow{\kappa} 10$ ✓ $10 \xrightarrow{\gamma} 11$ ✓ $00 \leftrightarrow 01$ ✗

- Slow relaxation

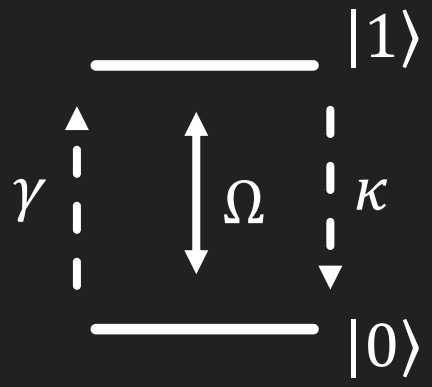
- Dynamical heterogeneity



Jäckle-Eisinger, Z. Phys. B (1991)
Sollich-Evans, PRL (1999)
Garrahan-Chandler, PRL (2002)

Open quantum East model

- Classical + transverse field



$$H = \Omega \sum_{k=1}^{N} \sigma_x^k$$

$$J_k^+ = \sqrt{\gamma}\sigma_k^+$$

$$J_k^- = \sqrt{\kappa}\sigma_k^-$$

- One spin case:

$$\rho_{ss} = \lambda_{\mathbf{E}}|\mathbf{E}\rangle\langle\mathbf{E}| + \lambda_{\mathrm{u}}|\mathrm{u}\rangle\langle\mathrm{u}|$$

Olmos-Lesanovsky-Garrahan, PRL (2012)
Lesanovsky-Horssen-Guta-Garrahan, PRL (2013)

Open quantum East model

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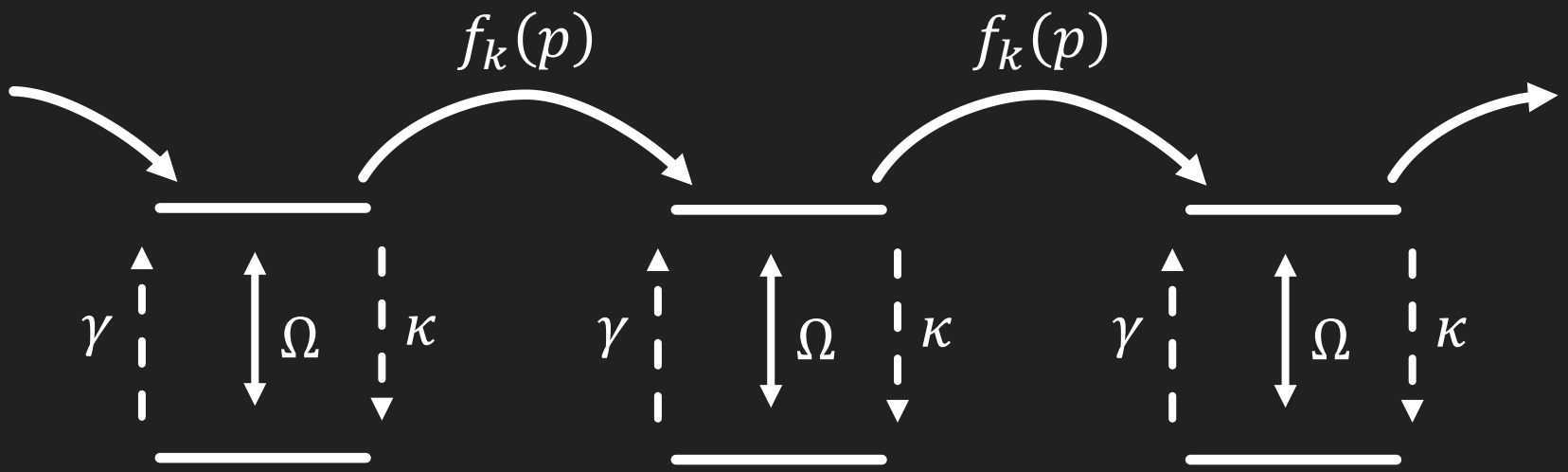


- One spin case:

$$\rho_{ss} = \lambda_{\mathbf{E}}|\mathbf{E}\rangle\langle\mathbf{E}| + \lambda_{\mathrm{u}}|\mathrm{u}\rangle\langle\mathrm{u}|$$

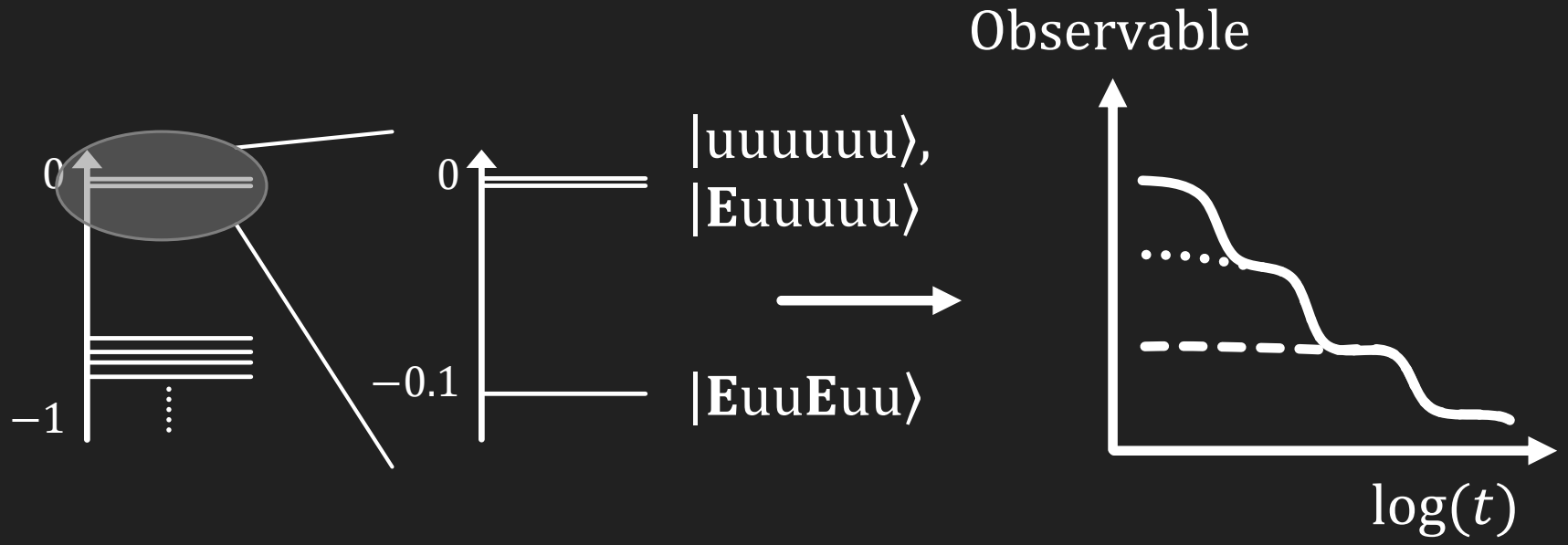
Constraint:

$$f_k(p) = p|\mathbf{E}\rangle_k\langle\mathbf{E}|_k + (1-p)I$$

Olmos-Lesanovsky-Garrahan, PRL (2012)
Lesanovsky-Horssen-Guta-Garrahan, PRL (2013)

Open quantum East model: hierarchy

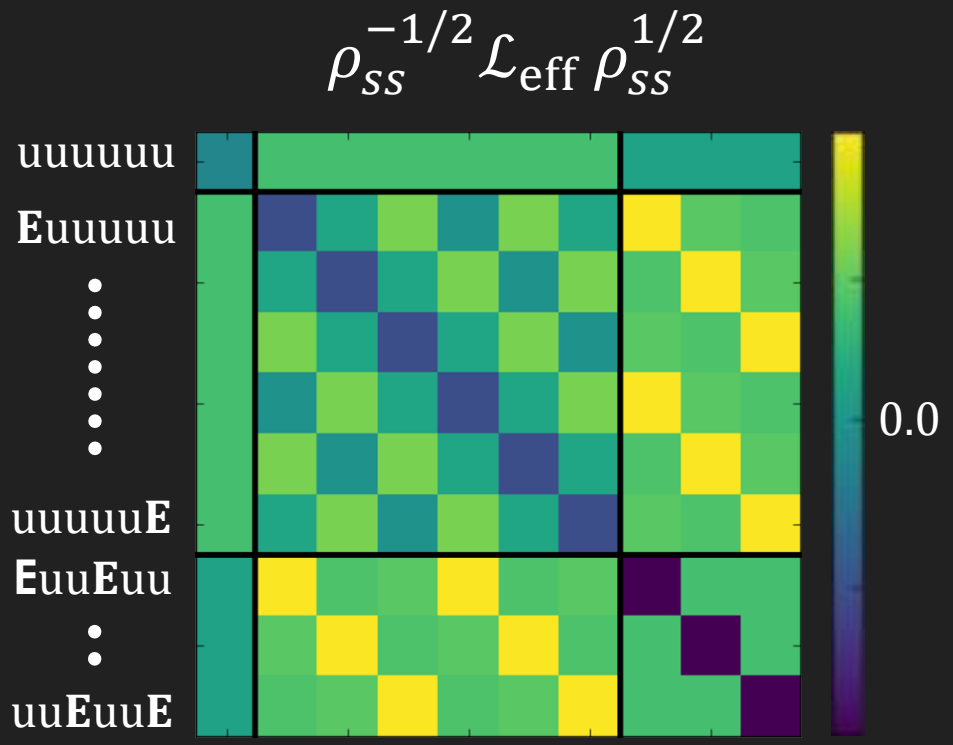
- Hierarchy of timescales (e.g. 6 sites)



DCR-Macieszczak-Lesanovsky-Garrahan, in preparation

Open quantum East model: effective dynamics

- Detailed balance
- Effective energy interaction independent



DCR-Macieszczak-Lesanovsky-Garrahan, in preparation

Conclusion

- Metastability in; open quantum Ising model, open quantum East model
- Theory provides understanding of relevant long time states and dynamics between them
- Appears as intermittence in trajectories
- Ideas apply to dynamical nuclear polarization, arXiv:1703.07159

Open quantum East model

- Coherent dynamics:

$$H = \Omega \sum_{k=1}^{N} \sigma_x^k f_{k+1}^2(p)$$

- Dissipative dynamics:

$$L_k^+ = \sqrt{\gamma}\sigma_k^+ f_{k+1}(p)$$

$$L_k^- = \sqrt{\kappa}\sigma_k^- f_{k+1}(p)$$

- One spin case:

$$\rho_{ss} = \lambda_e |e\rangle\langle e| + \lambda_u |u\rangle\langle u|$$

- Constraint:

$$f_k(p) = p|e\rangle_k\langle e|_k + (1-p)I$$