Phase transitions with global/ local dissipation

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Outline

- Properties of phase transitions/master equations
- Local/global master equations
- Phase transition consideration for the weak coupling Dicke Hamiltonian

Phase transitions

Phase transitions

Textbook: continuous phase transition

- Symmetry (breaking) of the Hamiltonian cause phase transition
- Scaling parameters $f(g) \propto |\lambda - \lambda_c|^{-\nu}$ characterise the PT
- Critical exponent ν determined by the system's PT-class
- For closed systems

Nonequilibrium phase transitions

- Generally experiments are done with open systems
- (Driven) dissipative effects compete with symmetries: new/change of phase transition
- Example: Cold atoms (Dicke model)

Experiments:

Ott et al, Phys. Rev. Lett. **116**, 235302 (2016)

Weatheril et al, Phys. Rev. Lett. **111**, 113901 (2013)

Esslinger et al, PNAS **110**, 11763 (2013)

Theory:

Nagy, Domokos, PRL **115**, 043601 (2015)

Zoller et al, Nature Phys. **4**, 878 (2008)

Zoller et al, PRL **105**, 015702 (2010)

Dicke phase transitions

Dicke model:

$$H_s = \omega_1 a^\dagger a + \omega_2 \sum_{i=1}^{N} \sigma_{z,i} + \sum_{i=1}^{N} \lambda (a + a^\dagger)(\sigma_i^+ + \sigma_i^-)$$

$$\lambda_c = \sqrt{\omega_1 \omega_2}/2$$

Scaling parameter:

$$\langle a^\dagger a \rangle \propto (\lambda_c - \lambda)^{-\gamma_a},\ \langle J_z \rangle \propto (\lambda_c - \lambda)^{-\gamma_n}$$

R. H. Dicke, Phys. Rev. **93**, 99 (1954).

Domokos et al. PRA 84 0436 (2011)

Change of critical exponents

Theory

Closed dynamics:

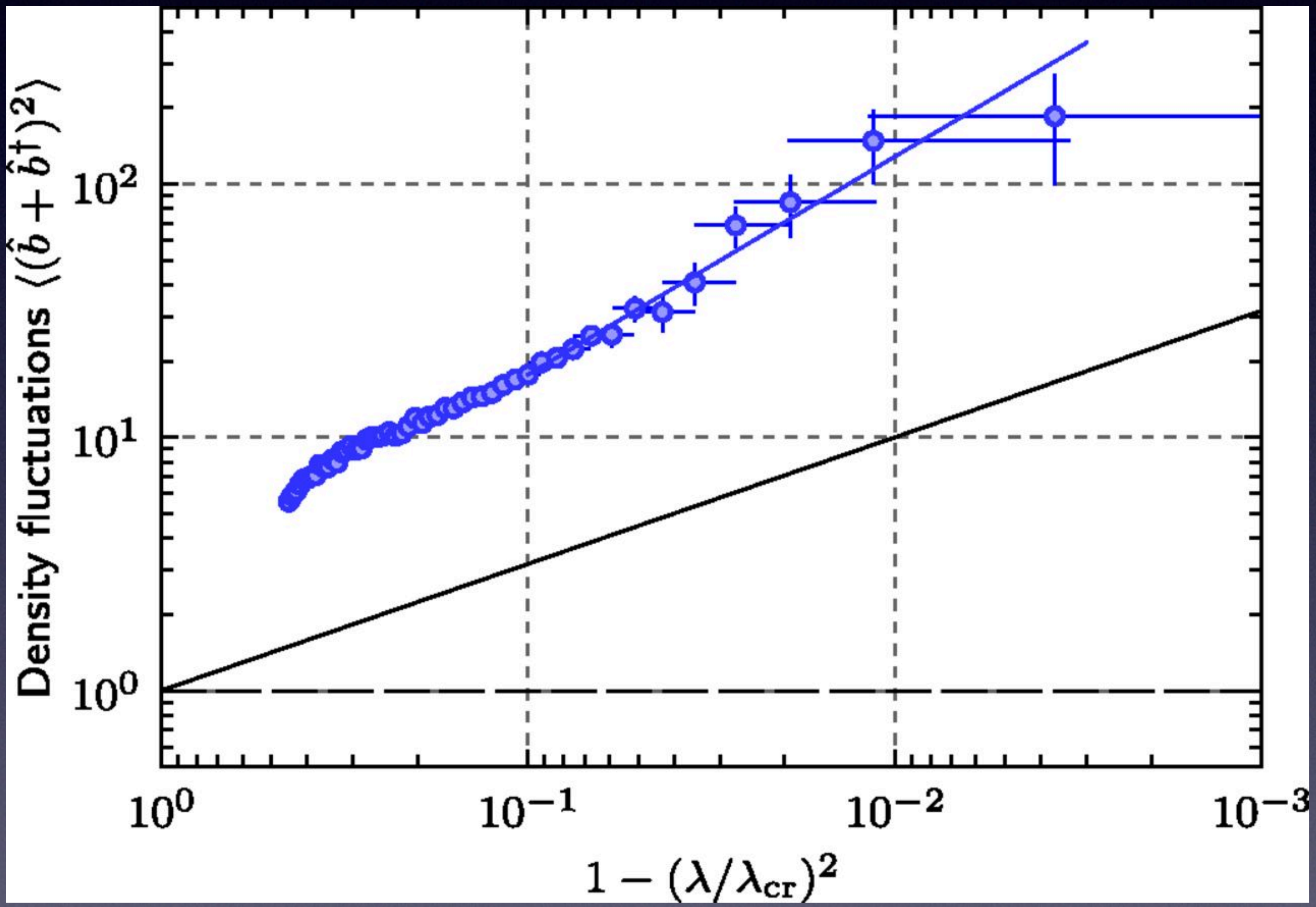
$$\gamma_a = \gamma_n = \frac{1}{2}$$

Open dynamics:

$$\gamma_a = \gamma_n = 1$$

Nagy, Domokos, PRL **115**, 043601 (2015)

Experiment



Esslinger et al, PNAS **110,** 29, 11763-11767 (2013)

Master equations

Master equations

- Weak system bath coupling
- Lindblad master equation

$$\dot{\rho} = -i[H_s, \rho] + \sum_i \mathcal{D}_{A_i}[\rho]$$

$$\mathcal{D}_{A_i}[\rho] = \Gamma_i \left(A_i \rho A_i^\dagger - \frac{1}{2}\{A_i^\dagger A_i, \rho\} \right)$$

Two-level system

$$\dot{\rho} = -\frac{i\omega_0}{2}[\sigma_z, \rho] + \mathcal{D}_{\sigma_+}\rho + \mathcal{D}_{\sigma_-}\rho$$

Laser mode

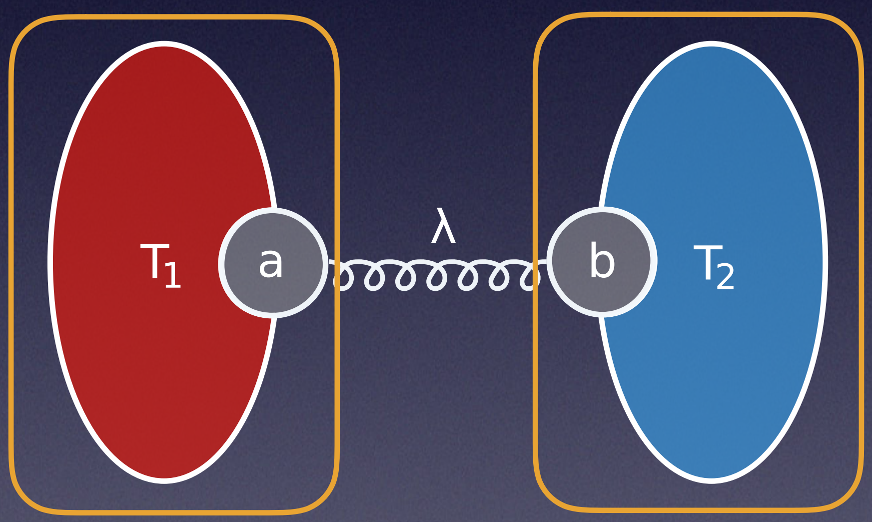
$$\dot{\rho} = -i\omega[a^\dagger a, \rho] + \mathcal{D}_a \rho + \mathcal{D}_{a^\dagger}\rho$$

Local/ global approach

Local Master equations

Problems:

- Involved derivation.
- H_s -dependent dissipators.

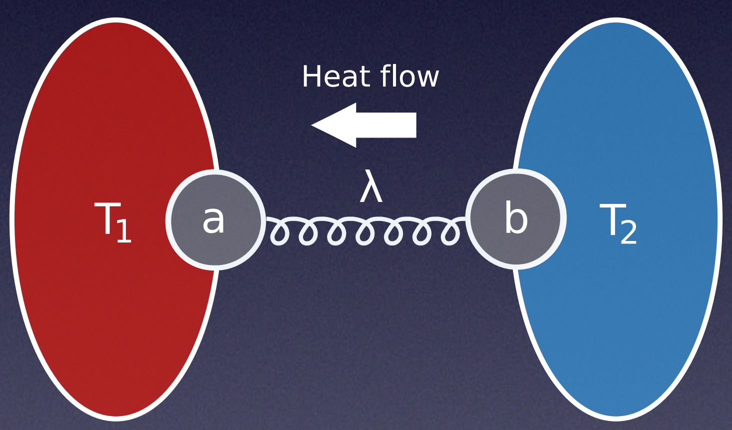


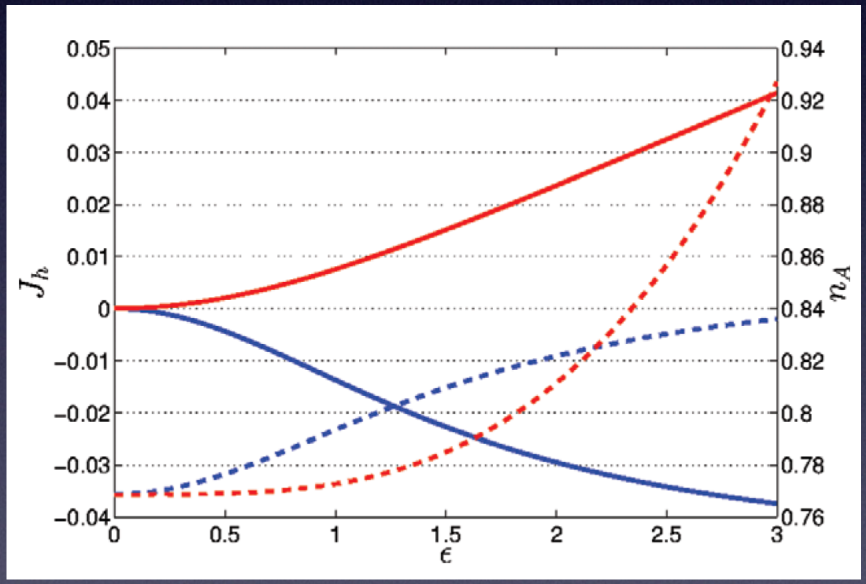
Solution:

- Derive dissipators locally according to expected processes.

Shortcomings of the local approach

- Local approach breaks down for strong inter-system coupling
- Possible violation of second law of thermodynamics





- Quantitatively small heat current from hot to cold
- Reconciliation: Gabriele De Chiara's talk

Adesso et al, Open Systems & Information Dynamics **24**, 04, 1740010 (2017)
Brunner et al, New J. Phys. **19,** 123037 (2017)
Levy, Kosloff, EPL **107**, 2 (2014)

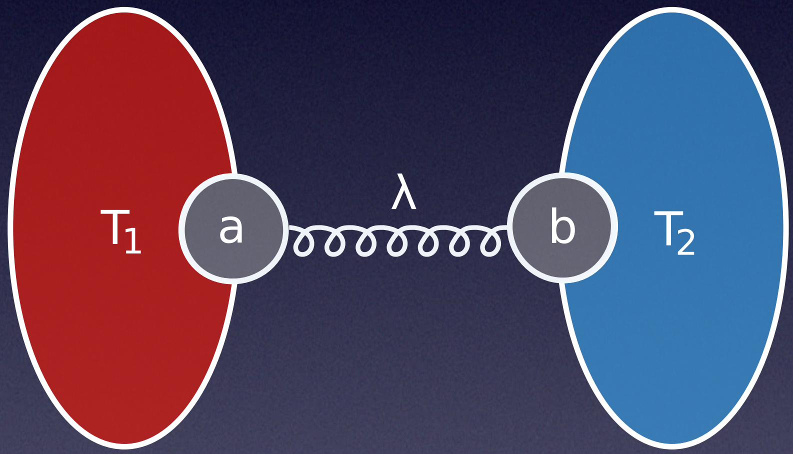
Phase transition differences

Weak coupling Dicke model

RWA Dicke Hamiltonian:

$$H_s = \omega_1 a^\dagger a + \omega_2 \sum_{i=1}^{N} \sigma_{z,i} + \sum_{i=1}^{N} \lambda(a\sigma_i^+ + a^\dagger \sigma_i^-)$$

Hepp, Lieb, Ann. Phys. **76** 360 (1973): $\lambda_c = \sqrt{\omega_1 \omega_2}$



Map of system in limit $N \to \infty$
Holstein-Primakoff transformation:

$$H_s = \omega_1 a^\dagger a + \omega_2 b^\dagger b + \lambda(ab^\dagger + a^\dagger b),\ \lambda \leq \lambda_c$$

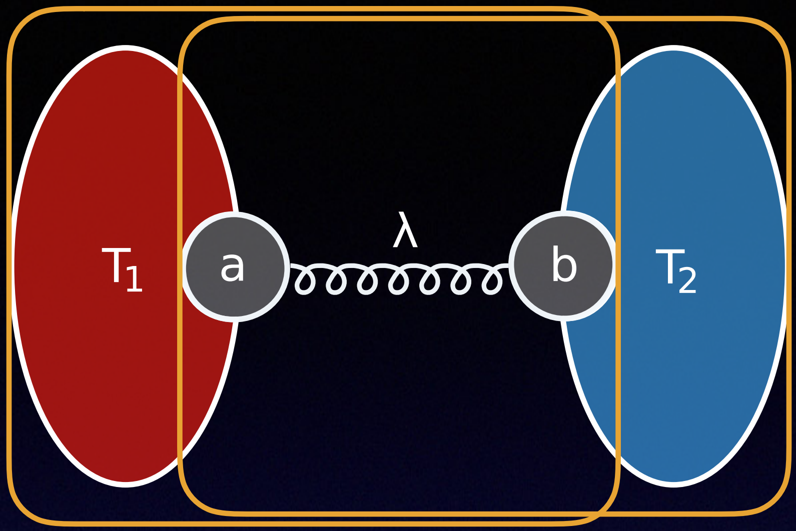
Local ME: $\dot{\rho} = -i[H_s, \rho] + \mathcal{D}_a[\rho] + \mathcal{D}_{a^\dagger}[\rho] + \mathcal{D}_b[\rho] + \mathcal{D}_{b^\dagger}[\rho]$

Emary, Brandes, PRE **67**, 066203 (2003)

Global treatment

Global phase transition

- Derive ME mathematically
- Global RWA Dicke master equation



$$\dot{\rho} = -i[H_s, \rho] + \mathcal{D}_a[\rho] + \mathcal{D}_{a^\dagger}[\rho] + \mathcal{D}_b[\rho] + \mathcal{D}_{b^\dagger}[\rho]$$

$$+\mathcal{D}_{a+b}[\rho] + \mathcal{D}_{a^\dagger+b^\dagger}[\rho]$$

Modification:

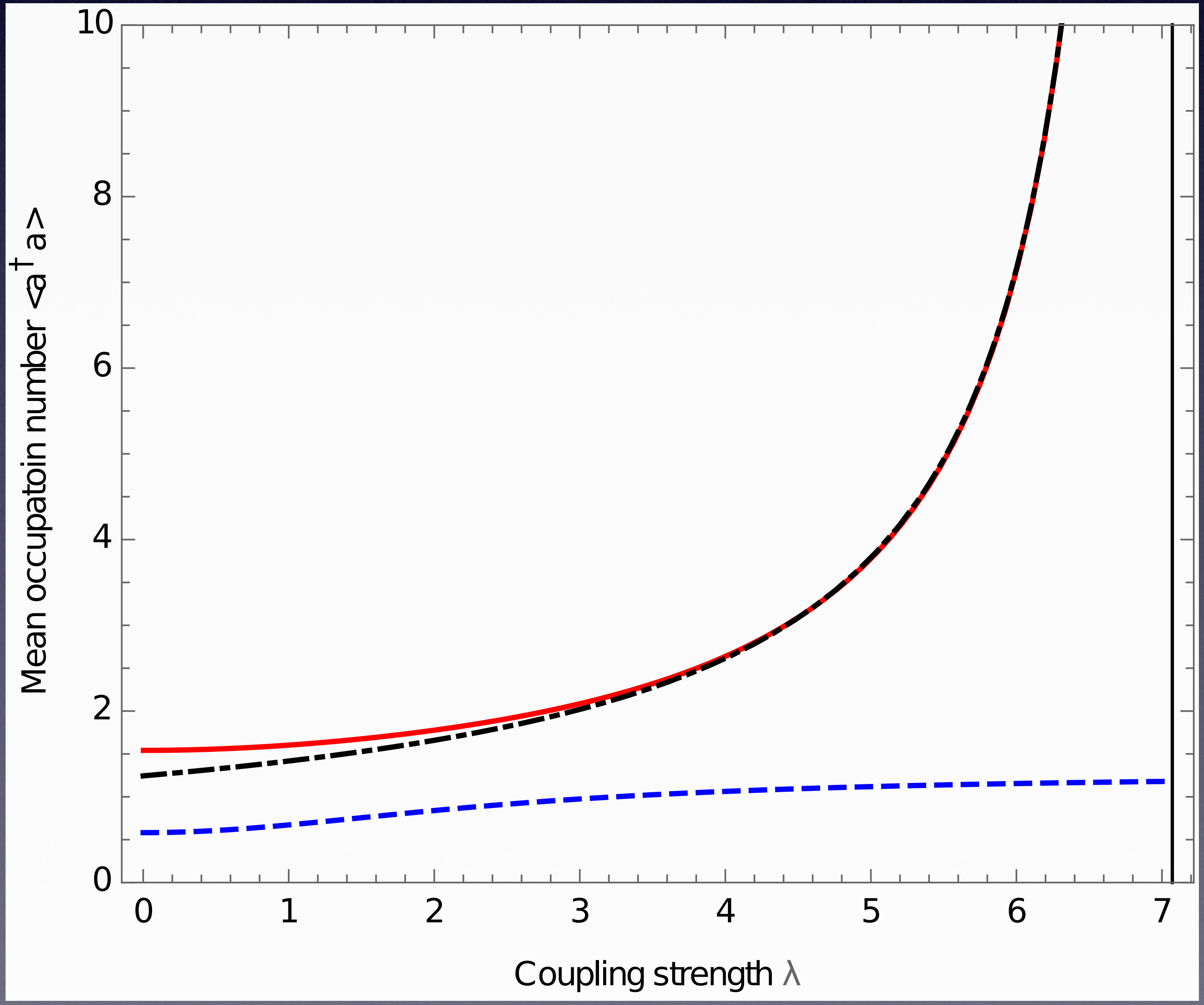
Additional nonlocal dissipators

$$\Gamma_i = \Gamma_i(\lambda)$$

Measures of phase transitions

Red: global Blue: local

$$\langle a^\dagger a\rangle \propto (\lambda_c - \lambda)^{-\gamma_a},\ \gamma_a = 1$$

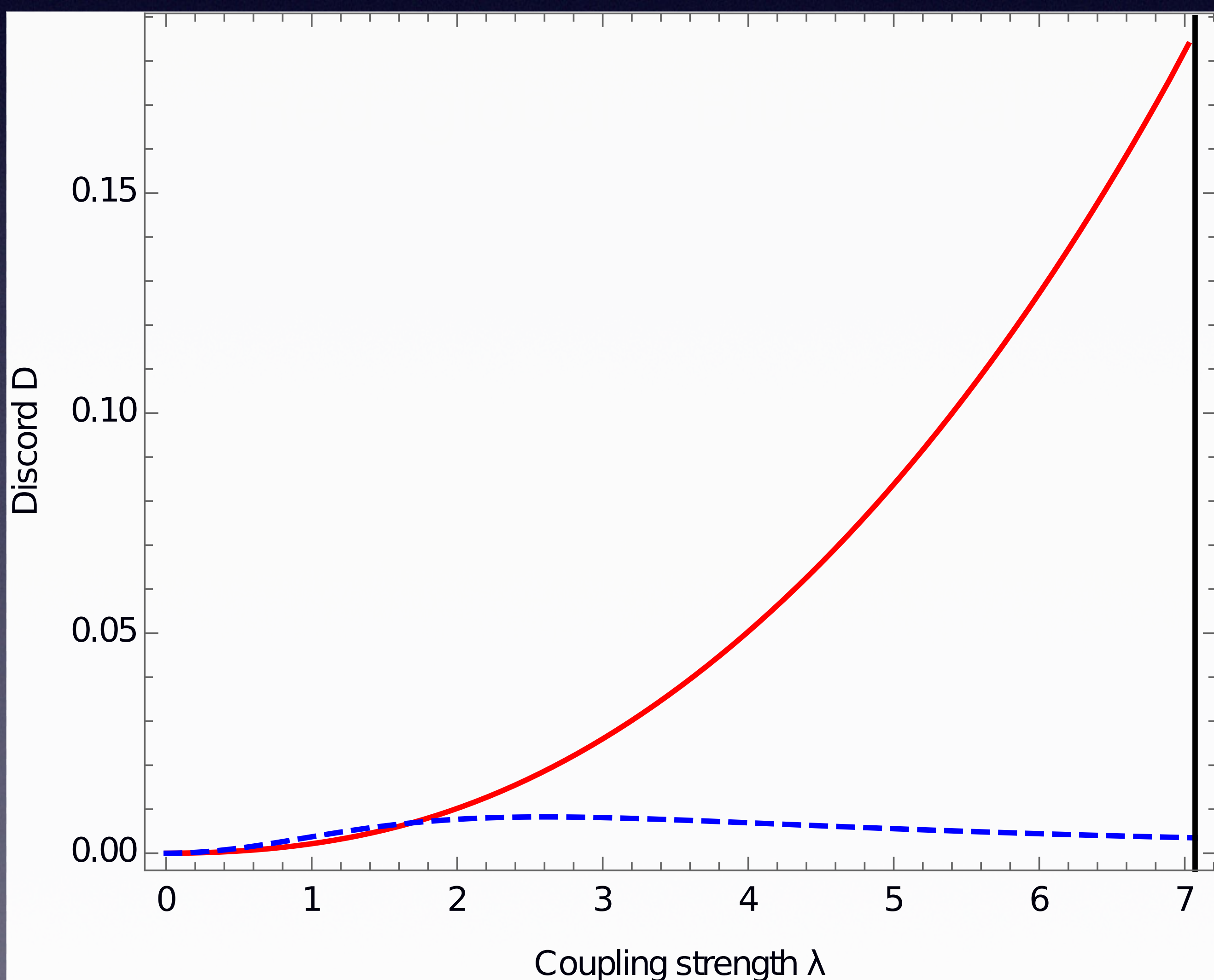


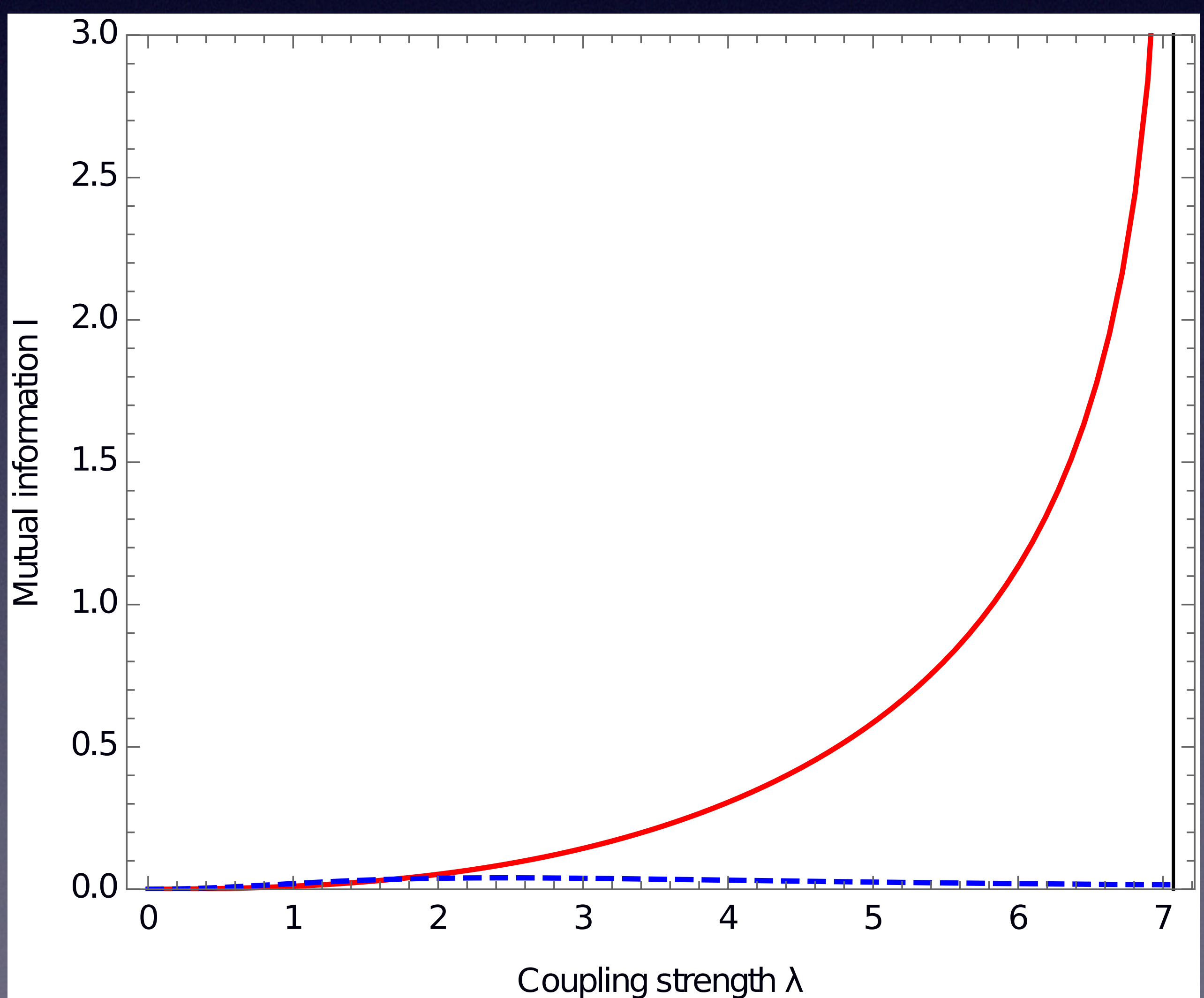
Measures of phase transitions

Subsystems become correlated close to phase transition

Fazio et al, Nature **416**, 608–610 (2002)   Dillenschneider, Phys. Rev. B **78**, 224413 (2008)

Discord: Quantum correlations, Mutual information: correlations





Conclusion

Conclusion

- Phase transitions may be described in the global approach, but local may fail to do so
- Local and global ME can have different effects on the structure of the phase transitions of the system