FT

Spin fluctuations in the dissipative phase transitions of the quantum Rabi model

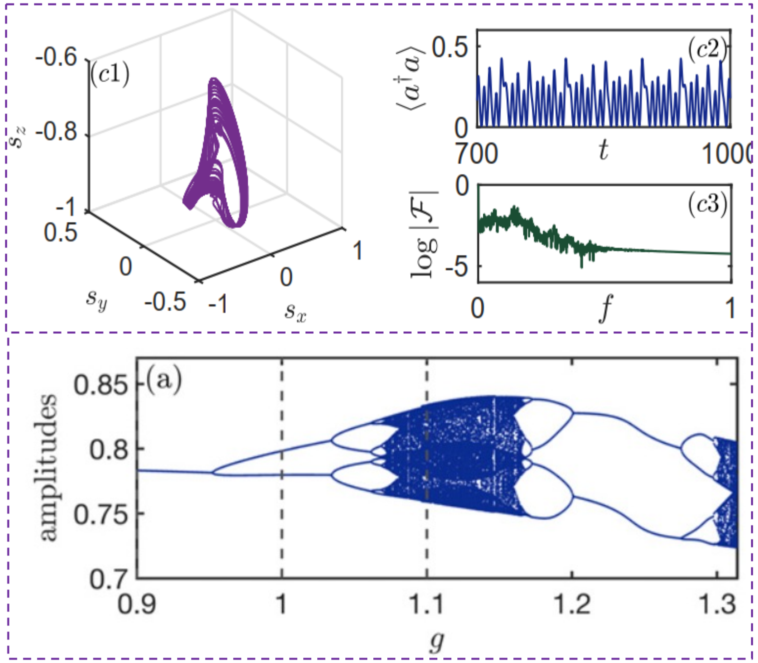
Reporter: Jiahui Li jiahuili@henu.edu.cn

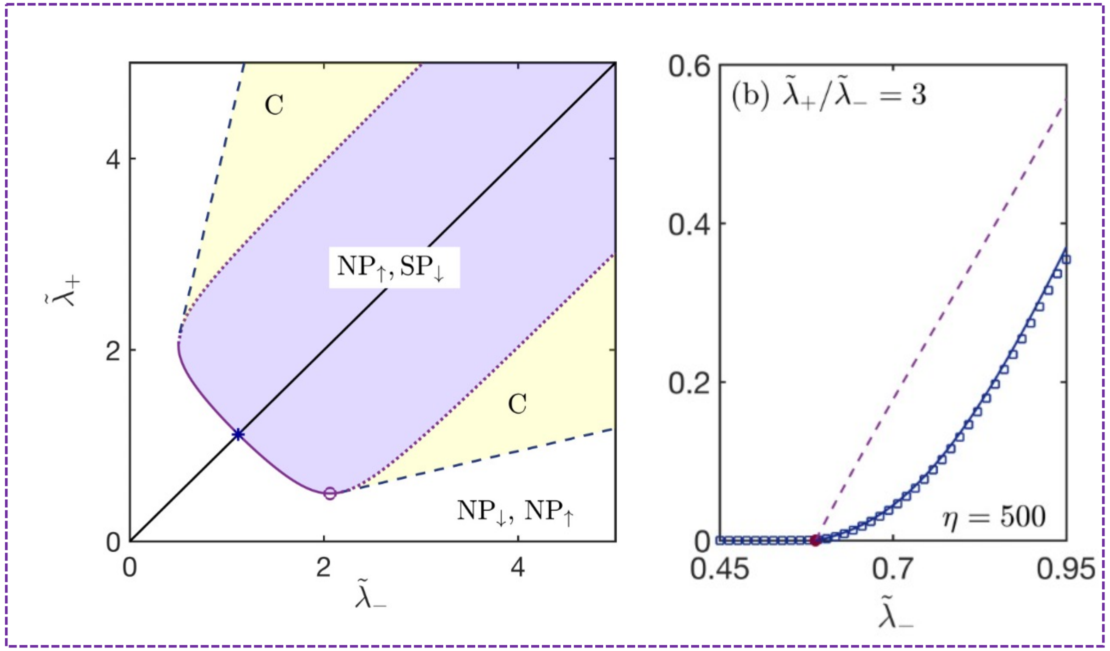
Collaborator: Stefano Chesi (CSRC)
Yingdan Wang (ITP)
Rosario Fazio (ICTP)

2 Research Interests

I. Simi-classical chaos in cavity QED systems

II. Dissipative quantum phase transition in Dicke and Rabi model





Reference: [1] Jiahui Li, Stefano Chesi, *PhysRevA.109.053702(2024)*.

[2] Jiahui Li, Rosario Fazio, and Stefano Chesi, *New J.Phys. 24.083039 (2022).*

[3] Jiahui Li, Rosario Fazio, Yingdan Wang and Stefano Chesi, *PhysRevResearch.6.043250 (2024)*

03

Dissipative quantum phase transition of Rabi model

A. Background and motivation

B. Mean-field analysis

C. Finite η effect on DQPT – beyond mean-field treatment

D. Scaling analysis at the second-order phase transition

E. Conclusion

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A. Research background ---- Models

Hamiltonian: $\hat{H} = \omega_c \hat{a}^\dagger \hat{a} + \sum_{i=1}^{N} \frac{\Omega}{2}\hat{\sigma}_z - \sum_{i=1}^{N} [\lambda_- (\hat{a}\hat{\sigma}_+ + \hat{a}^\dagger \hat{\sigma}_-) + \lambda_+ (\hat{a}\hat{\sigma}_- + \hat{a}^\dagger \hat{\sigma}_+)],$

Rabi model: $N = 1$ Dicke model: $N \gg 1$

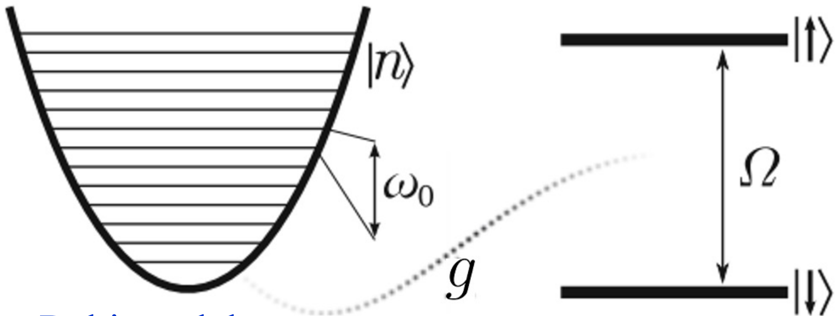
anisotropy: $r = \lambda_+/\lambda_- \neq 1$

Symmetry: Z2 parity symmetry,

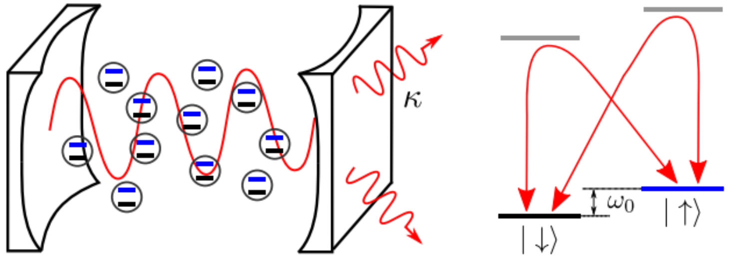
invariant $\{a \to -a, \quad \sigma_- \to -\sigma_-\}$

Rabi model: $[\hat{H}, e^{i\pi\hat{n}}] = 0, \hat{n} = \hat{a}^\dagger \hat{a} + \hat{\sigma}_z$

Dicke model: $[\hat{H}, e^{i\pi\hat{M}}] = 0, \hat{M} = \hat{a}^\dagger \hat{a} + \hat{J}_z + j$



Rabi model



Dicke model

A. Research background ---- Phase transition (PT)

- Thermodynamic limit :

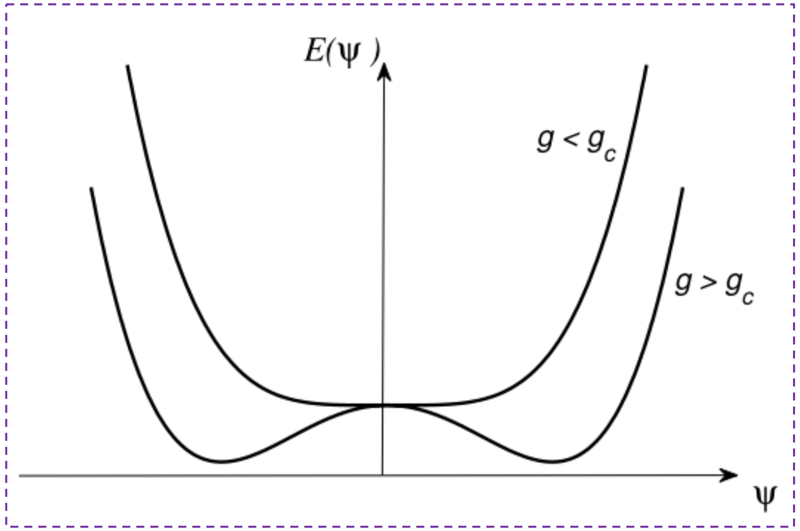
occurs in the system with a large number of particles, e.g., Dicke model;
also can defined in the non-thermodynamic systems, e.g., Rabi model.

$$N \to \infty \quad \text{(Dicke model)} \longrightarrow \quad \eta = \frac{\Omega}{\omega_c} \to \infty \quad \text{(Rabi model)}$$

- Order parameter :

the value of the order parameter by optimizing some energy functional.

$$\psi = \begin{cases} 0, & g < g_c, \\ \neq 0, & g > g_c. \end{cases}$$



A. Research background ---- Phase transition (PT)

Jonas Larson and Elinor K Irish
J. Phys. A: Math. Theor. ***50*** *(2017) 174002 (22pp)*

- Critical exponent:

determines how the *correlations behave* when close to the critical point;

$$A \propto |g - g_c|^{-v}. \qquad v: \ \textit{critical exponent}$$

- Scaling laws:

a set of *critical exponents*: $\alpha, \beta, \gamma, \delta.$

they are not all independent from one another.

$$\alpha + 2\beta + \gamma \geq 2, \quad \alpha + \beta(\delta + 1) \geq 2$$

A. Research background ---- Phase transition (PT)

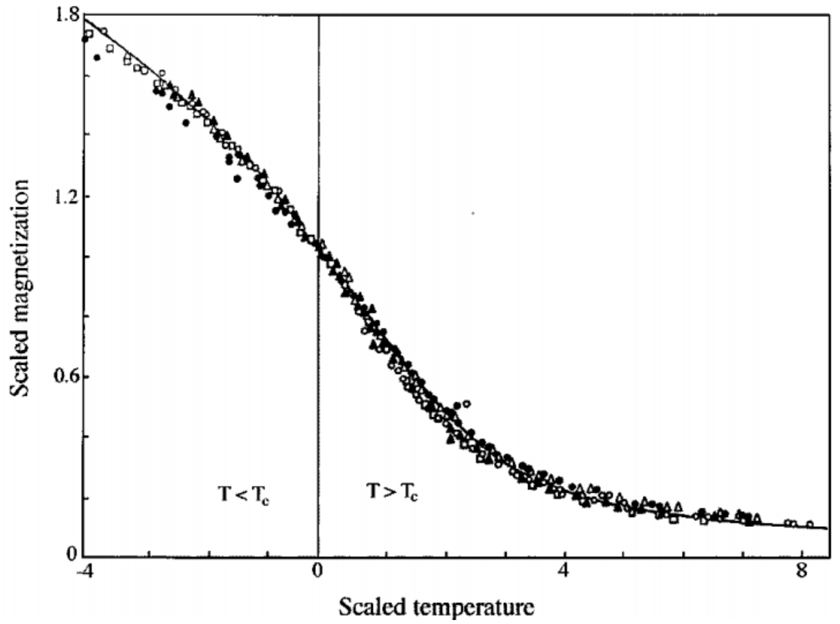
- Universality class:
  different systems have same *critical exponents*;

- Finite size scaling:

$$\chi(t, L) = L^{\gamma} f\left(tL^{1/v}\right).$$

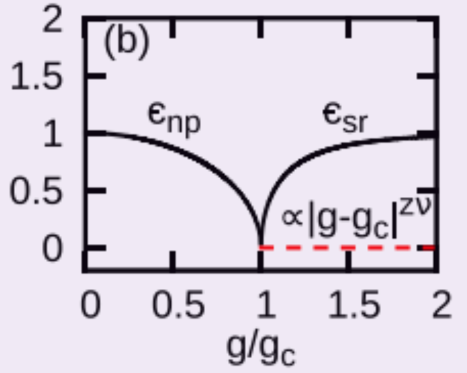
$$t = T - T_c.$$

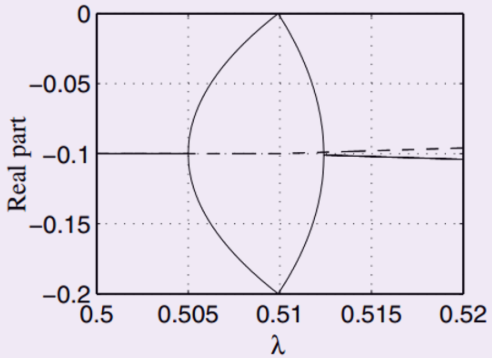
T : temperature
L : size of system



H. Eugene Stanley
Rev. Mod. Phys., Vol. 71, No. 2, Centenary 1999

	quantum phase transition (QPT)	dissipative QPT
System:	Hamiltonian $H = H^\dagger, \quad H\|\Psi\rangle = E_\Psi\|\Psi\rangle$	Liouvillian operator $\mathcal{L}\rho = \lambda_\rho \rho$
State:	ground state $H\|\Psi_0\rangle = E_{\Psi_0}\|\Psi_0\rangle$	steady state $\mathcal{L}\rho_0 = 0$
Mark of PT:	energy gap $\Delta = E_{\Psi_1} - E_{\Psi_0} = 0$	asymptotic decay rate $\kappa_{ADR} = \|\mathrm{Re}\,(\lambda_0)\| - \|\mathrm{Re}\,(\lambda_1)\| = 0$

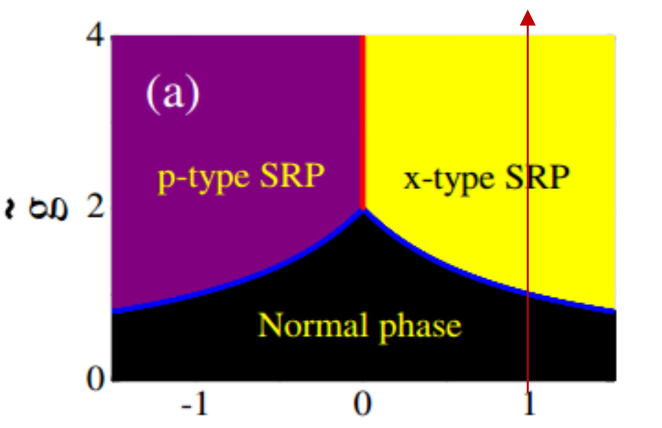




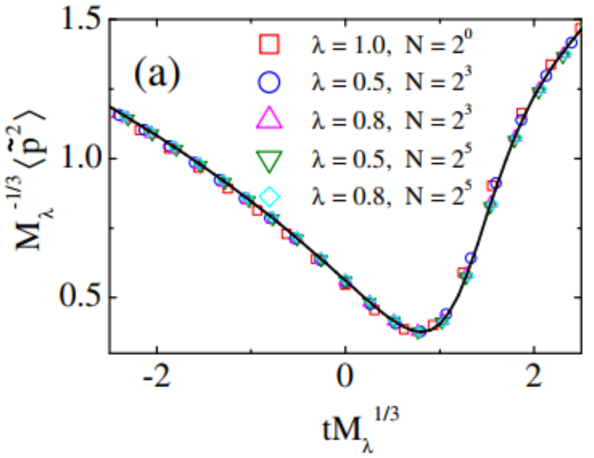
A. Research background -- Without dissipation

Hamiltonian:

$$\hat{H} = \omega_c \hat{a}^\dagger \hat{a} + \sum_{i=1}^{N} \frac{\Omega}{2} \hat{\sigma}_z - \sum_{i=1}^{N} [\lambda_- (\hat{a}\hat{\sigma}_+ + \hat{a}^\dagger \hat{\sigma}_-) + \lambda_+ (\hat{a}\hat{\sigma}_- + \hat{a}^\dagger \hat{\sigma}_+)],$$



$\lambda = 1$



- Plenio, PRL 115, 180404 (2015)

  QPT in the Rabi model: $N = 1, r = 1$

  - phase transition if $\eta = \dfrac{\Omega}{\omega_c} \to \infty$

- Hai-Qing Lin, PRL 119, 220601 (2017)

  QPT in the anisotropic Rabi and Dicke model: $N \geq 1, r \neq 1$

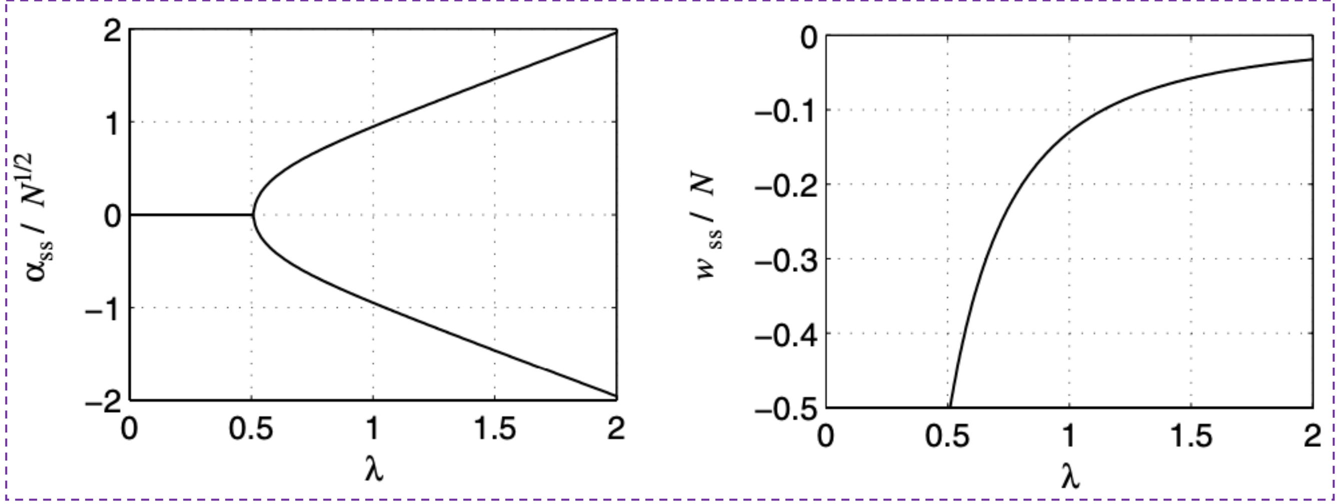
  - phase diagram
  - anisotropic Rabi and Dicke model belong to the same universality class

A. Research background -- With dissipation

Master equation:

$$\dot{\rho} = -i[H, \rho] + \kappa\mathcal{D}[a]$$

$$\mathcal{D}[a] = 2a\rho a^\dagger - a^\dagger a\rho - \rho a^\dagger a$$

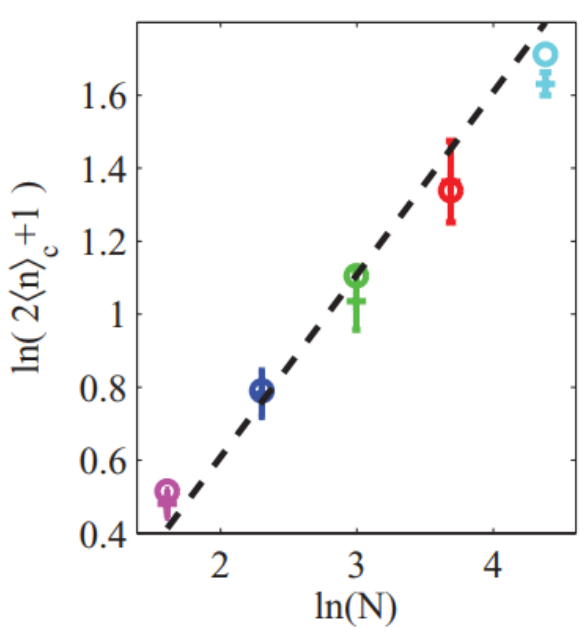


- F. Dimer, PhysRevA. **75**, 013804 (2007)

  DQPT in the Dicke model: $N \gg 1, r = 1$

- Philipp Strack, PRA87, 023831 (2013)

  Finite size scaling (analytical)

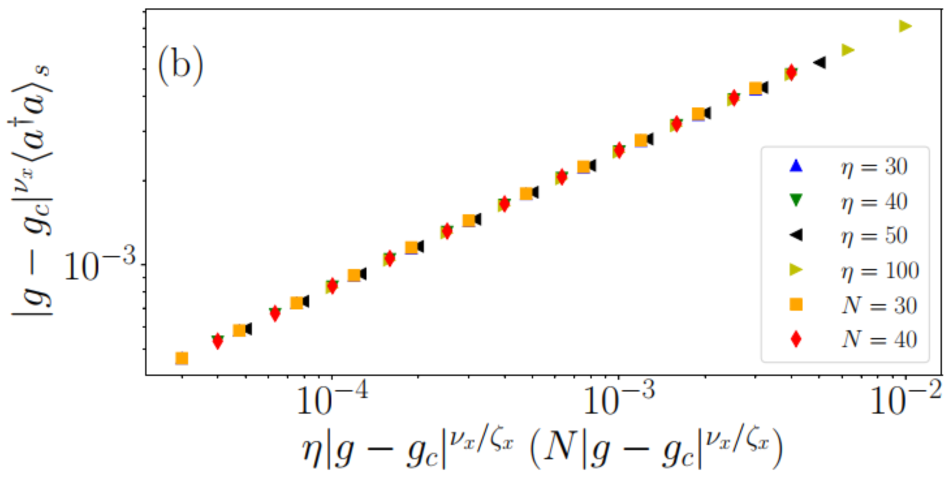


A. Research background -- With dissipation

- Plenio, PRA 97, 013825 (2018)

  DQPT in the Rabi model: $N=1, r=1$

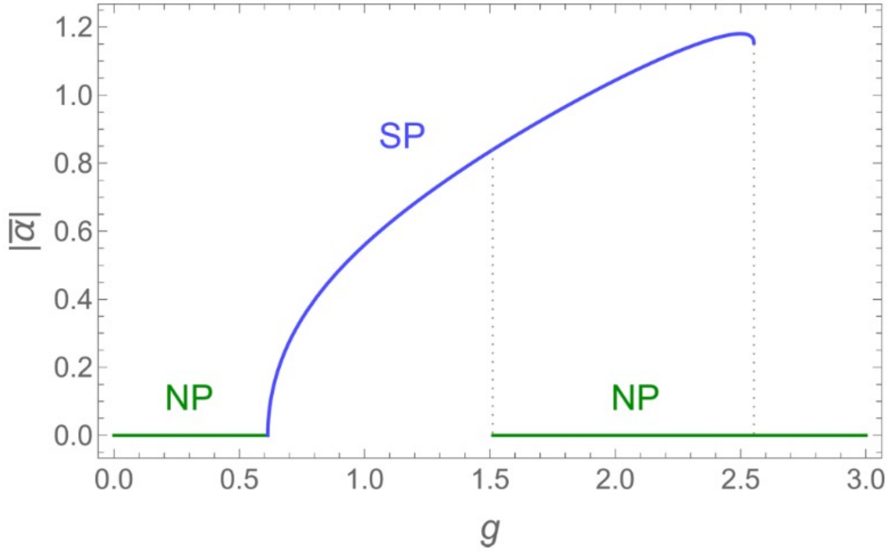
  - second-order phase transition
  - Rabi and Dicke model belong to the same universality class (numerical)



- Guitao Lyu, PhysRevResearch.6.033075(2024)

  Multicritical DQPT in the anisotropic Rabi model

  $N=1, r\neq 1$



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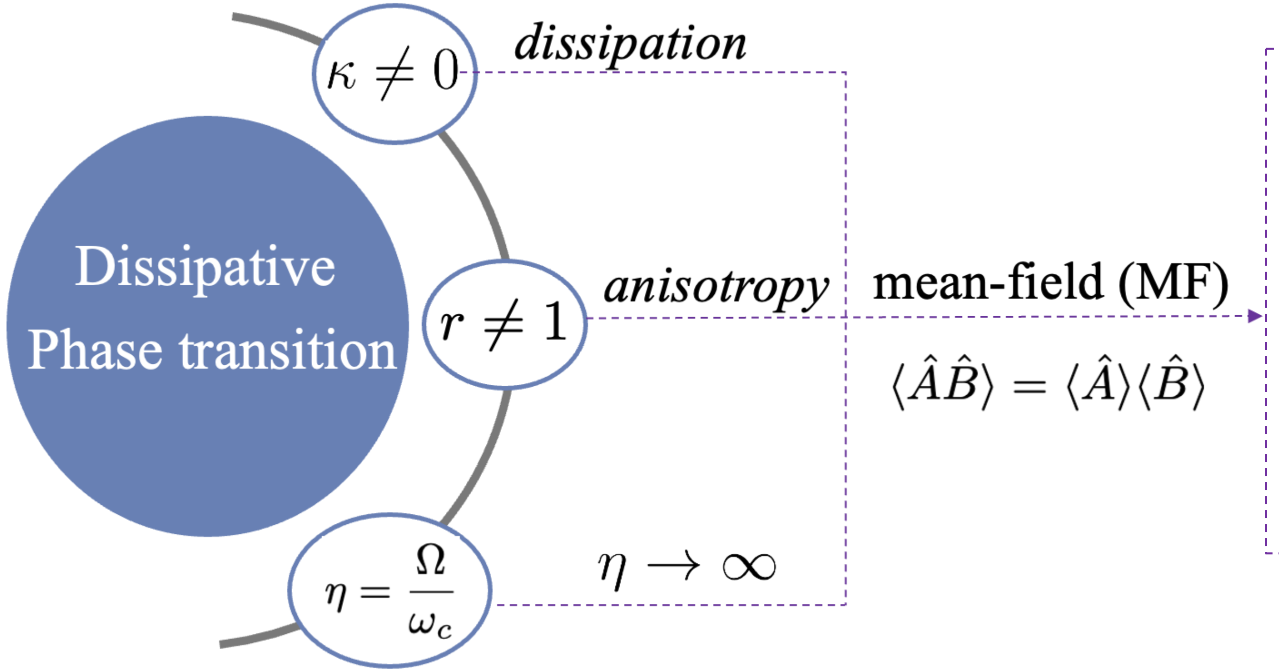
B. Mean-field analysis DQPT in AQRM

Hamiltonian: $\hat{H} = \omega_c \hat{a}^\dagger \hat{a} + \frac{\Omega}{2}\hat{\sigma}_z - \lambda_- \left(\hat{a}\hat{\sigma}_+ + \hat{a}^\dagger \hat{\sigma}_-\right) - \lambda_+ \left(\hat{a}\hat{\sigma}_- + \hat{a}^\dagger \hat{\sigma}_+\right),$

Master equation (ME): $\dot{\rho} = -i[H, \rho] + \kappa \mathcal{D}[a]$ $\quad r = \lambda_+/\lambda_-$



$$\frac{dc}{d\tau} = -\left(\frac{\kappa}{\omega_c} + i\right) c + \frac{i}{2}\left(\tilde{\lambda}_- s_- + \tilde{\lambda}_+ s_+\right),$$

$$\frac{1}{\eta}\frac{ds_+}{d\tau} = i\,\mathrm{sgn}(\Omega)\, s_+ + \frac{i}{2}\left(\tilde{\lambda}_- c^* + \tilde{\lambda}_+ c\right) s_z,$$

$$\frac{1}{\eta}\frac{ds_z}{d\tau} = i\tilde{\lambda}_- \left(c s_+ - c^* s_-\right) - i\tilde{\lambda}_+ \left(c s_- - c^* s_+\right)$$

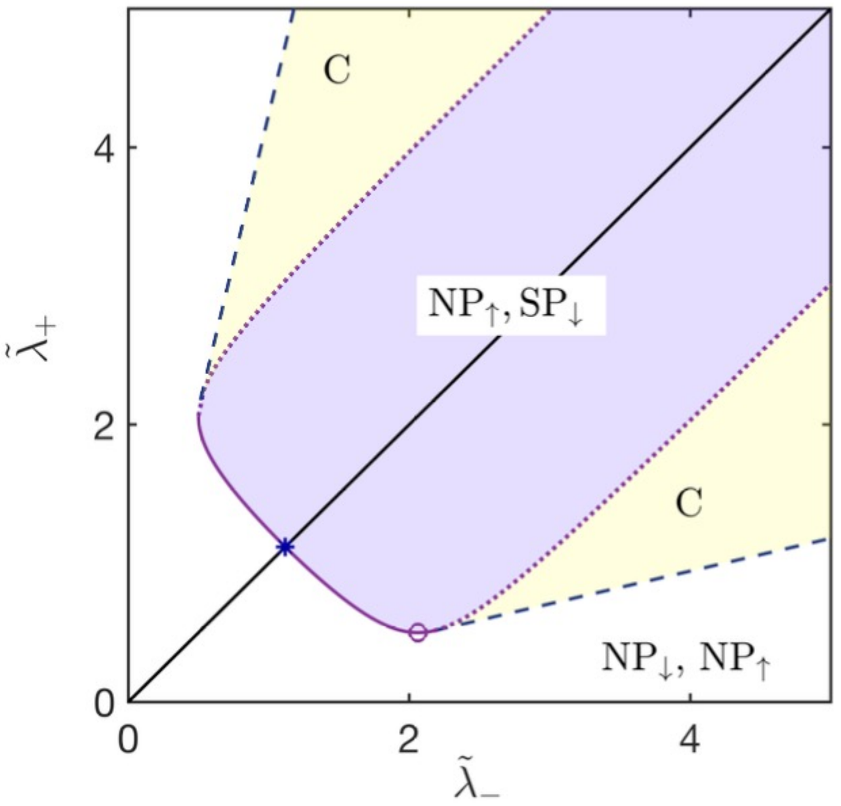
$a = \langle \hat{a} \rangle$, $s_\pm = \langle \hat{\sigma}_\pm \rangle$, and $s_z = \langle \hat{\sigma}_z \rangle$

$c = \frac{\langle \hat{a} \rangle}{\sqrt{\eta}}$, $\quad \tilde{\lambda}_\pm = \frac{2\lambda_\pm}{\omega_c \Omega}$

B. Mean-field analysis ---- Phase diagram

$$s_z = \pm \frac{1}{\sqrt{1+|\tilde{\lambda}_- c^* + \tilde{\lambda}_+ c|^2}}, \qquad s_+ = -\frac{1}{2}(\tilde{\lambda}_- c^* + \tilde{\lambda}_+ c) s_z,$$

$$\frac{dc}{d\tau} = -\left(\frac{\kappa}{\omega_c} + i\right) c - sgn[s_z] \frac{i}{4} \frac{(\tilde{\lambda}_-^2 + \tilde{\lambda}_+^2) c + 2\tilde{\lambda}_- \tilde{\lambda}_+ c^*}{\sqrt{1+|\tilde{\lambda}_- c^* + \tilde{\lambda}_+ c|^2}}.$$



Steady state:

$\mathrm{NP}_\downarrow : s_z = -1, \; s_+ = 0, \; c = 0,$ $\longrightarrow$ $\boxed{|0, \downarrow\rangle}$

$\mathrm{NP}_\uparrow : s_z = 1, \; s_+ = 0, \; c = 0.$ $\longrightarrow$ $\boxed{|0, \uparrow\rangle}$

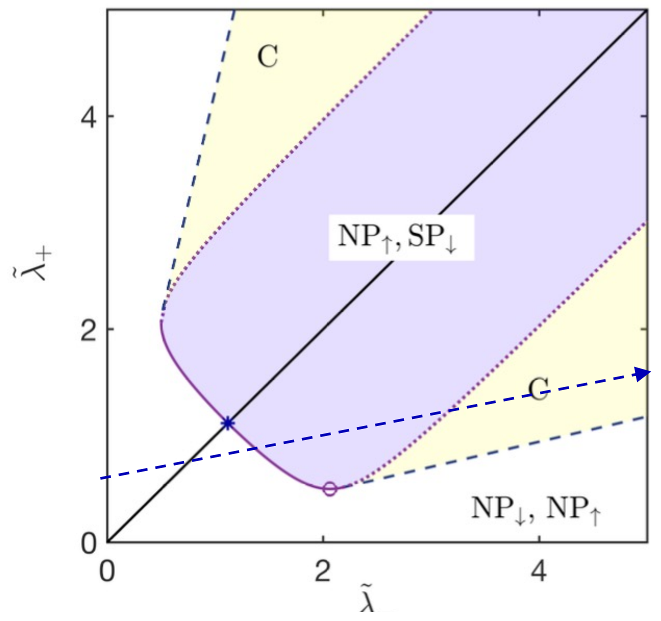
$$\mathrm{SP}_\downarrow : s_z = -\cos\theta_{\mathrm{SP}}, \quad s_+ = \pm\frac{1}{2} e^{i\phi_{\mathrm{SP}}} \sin\theta_{\mathrm{SP}}$$

$$c = \frac{\tilde{\lambda}_- s_- + \tilde{\lambda}_+ s_+}{2(1 - i\kappa/\omega_c)},$$ $\longrightarrow$ $\boxed{|\pm\alpha, \downarrow\rangle}$

unsteady fixed points:

$\mathrm{SP}_\uparrow :$ $\boxed{|\pm\alpha, \uparrow\rangle}$

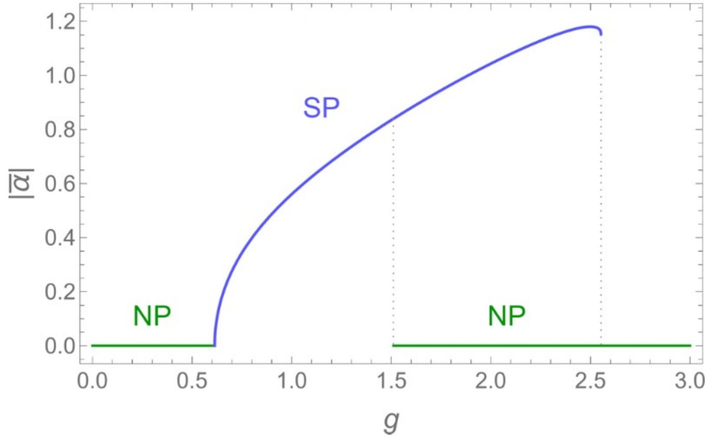
B. Mean-field analysis ---- Compare of MF and ME results



White: normal phase (NP)

Purple: super-radiant phase (SP)

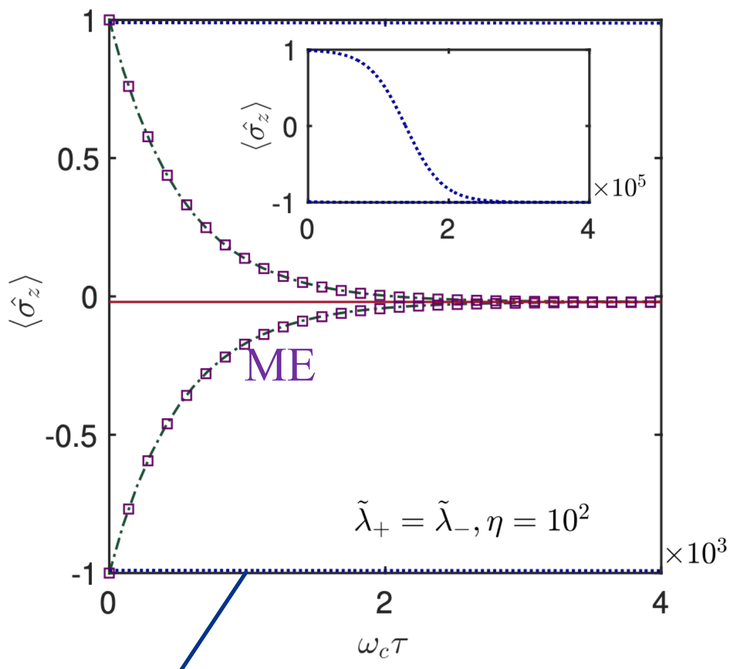
Yellow: coexistence phase



Master equation (ME):

$$\dot{\rho} = -i[H, \rho] + \kappa \mathcal{D}[a]$$

NP:



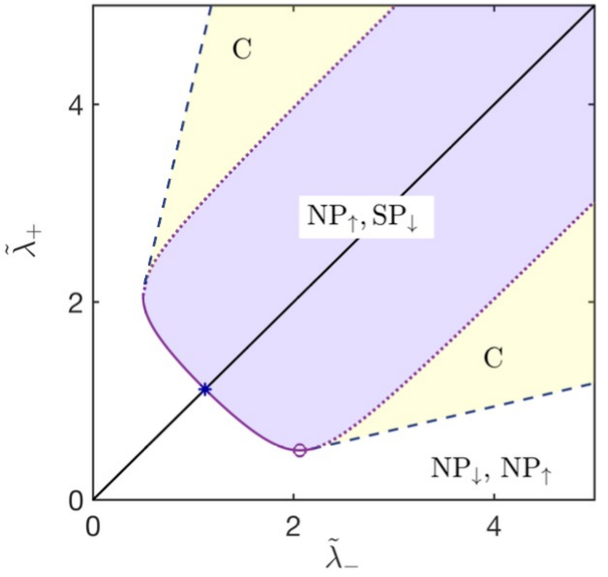
mean-field

PhysRevResearch.6.033075(2024)

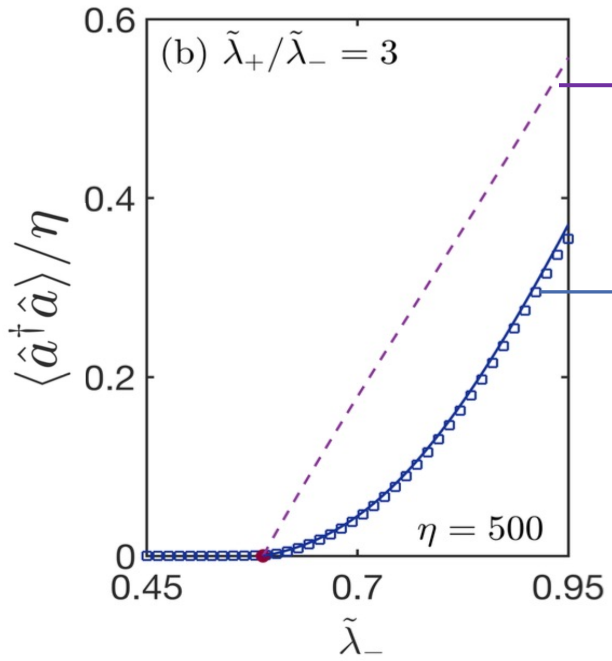
B. Mean-field analysis ---- Compare of MF and ME results

Mean-field (MF) approach ($\eta \to \infty$):

$$\langle AB \rangle = \langle A \rangle \langle B \rangle$$



Master equation (ME): $\dot{\rho} = -i[H, \rho] + \kappa \mathcal{D}[a]$



mean-field

ME

SP

MF analysis and numerical simulation of ME:

- meet at basic information about DQPT;

  (phase boundary, critical points)

- show discrepancy at predicting observable quantity;

  (qubit population, photon number)

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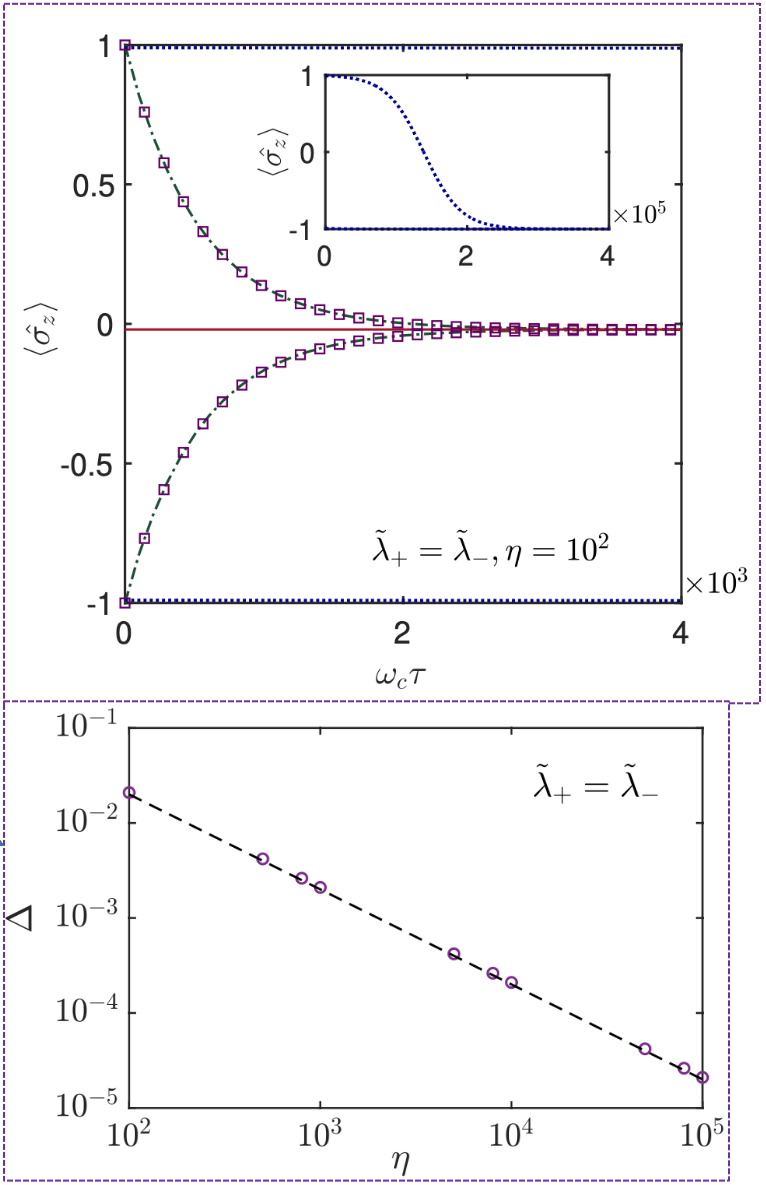
C. Finite η effects ---- cumulant expansion

$$\frac{d\langle\sigma_z\rangle}{dt} = 2ig\left[\langle\hat{a}\sigma_+\rangle - \langle\hat{a}^\dagger\sigma_-\rangle - \lambda\left(\langle\hat{a}\sigma_-\rangle - \langle\hat{a}^\dagger\sigma_+\rangle\right)\right]$$

$$\frac{d\langle\hat{a}\sigma_+\rangle}{dt} = -\left(\kappa + i\omega_0 - i\Omega\right)\langle\hat{a}\sigma_+\rangle + ig\left(\langle\hat{a}^\dagger\hat{a}\sigma_z\rangle + \lambda\langle\hat{a}^2\sigma_z\rangle + \langle\sigma_+\sigma_-\rangle\right)$$

$$\vdots$$



Cumulant expansion:

$$\langle ABC\rangle = \langle AB\rangle\langle C\rangle + \langle AC\rangle\langle B\rangle + \langle BC\rangle\langle A\rangle - 2\langle A\rangle\langle B\rangle\langle C\rangle.$$

Analytical result in NP: $\langle\hat{\sigma}_z\rangle \simeq \dfrac{\lambda_+^2 - \lambda_-^2}{\lambda_-^2 + \lambda_+^2} + \Delta,$

$\Delta \sim 1/\eta$

Statistical mixture of $\mathrm{NP}_\uparrow$ and $\mathrm{NP}_\downarrow$:

$$P_\pm = \frac{\lambda_\pm^2}{\lambda_+^2 + \lambda_-^2}. \quad \text{(normal phase)}$$

Controlled by $\lambda_\pm$ or r

Disadvantage:

complex calculation, hard to get the analytical result in SP;

C. Finite η effects ---- effective master equation

Master equation:

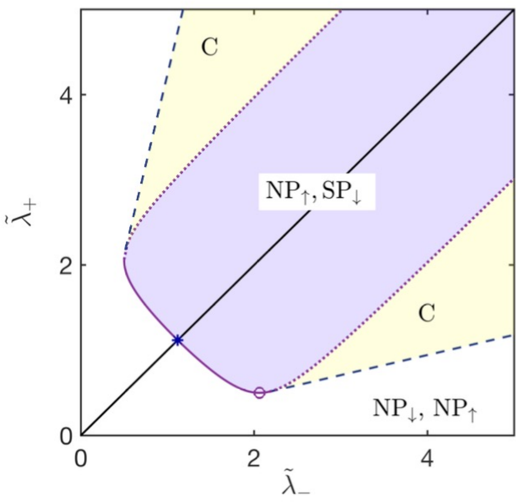
$$\dot{\rho} = -i[H, \rho] + \kappa \mathcal{D}[a] \xrightarrow{U^\dagger \rho U} \text{effective master equation}$$

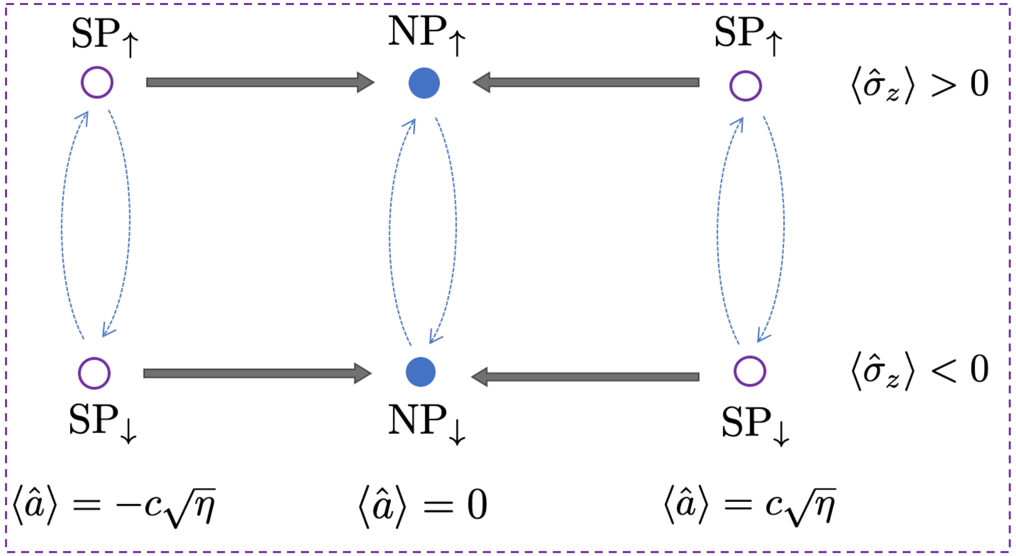
NP: $\hat{\tilde{\rho}} = \hat{U}_{np}^\dagger \hat{\rho} \hat{U}_{np}$

$$\dot{\hat{\tilde{\rho}}} = -i\left[\hat{H}_{np}, \hat{\tilde{\rho}}\right] + \kappa \mathcal{D}[\hat{a}]\hat{\tilde{\rho}} + \frac{\kappa}{4\eta}\sum_{\mu=\pm} \tilde{\lambda}_\mu^2 \mathcal{D}[\hat{\sigma}_\mu]\hat{\tilde{\rho}}.$$

$$\left.\begin{aligned} \Gamma_{\mathrm{NP}_\uparrow \to \mathrm{NP}_\downarrow} &= \frac{\tilde{\lambda}_-^2}{2\eta}\kappa, \\ \Gamma_{\mathrm{NP}_\downarrow \to \mathrm{NP}_\uparrow} &= \frac{\tilde{\lambda}_+^2}{2\eta}\kappa \end{aligned}\right\} \langle \hat{\sigma}_z \rangle \simeq \frac{\lambda_+^2 - \lambda_-^2}{\lambda_-^2 + \lambda_+^2}$$

$$\hat{\tilde{\rho}} = P_+ \hat{\rho}_{c,\uparrow} |\uparrow\rangle\langle\uparrow| + P_- \hat{\rho}_{c,\downarrow} |\downarrow\rangle\langle\downarrow|,$$





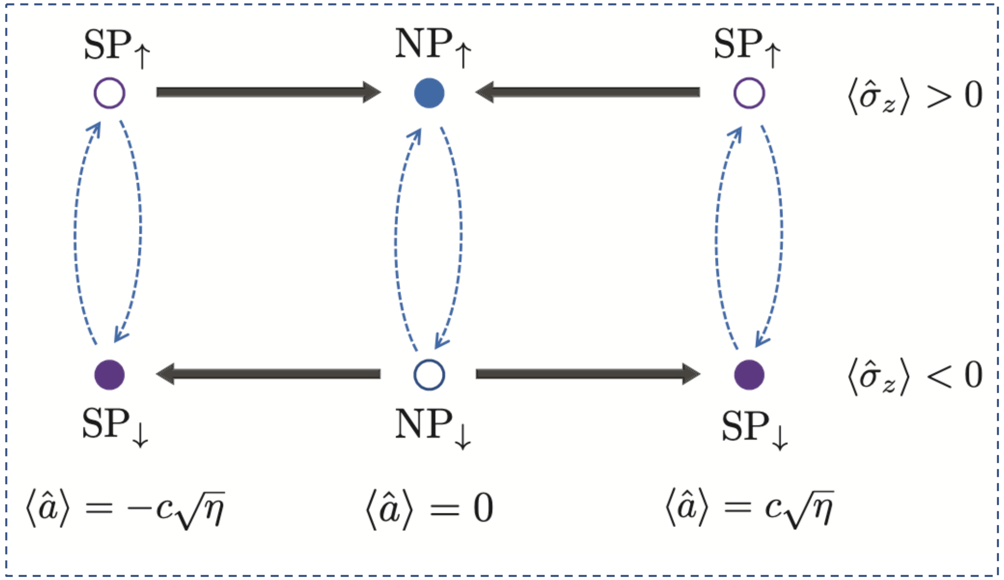
C. Finite η effects ---- effective master equation

Our work

SP: $$\dot{\hat{\tilde{\rho}}} = -i\left[\hat{H}_{sp}, \hat{\tilde{\rho}}\right] + \kappa\mathcal{D}[\hat{a}]\hat{\tilde{\rho}} + \frac{\kappa}{4\eta}\cos^2\theta_{\mathrm{SP}}\left(|\tilde{\chi}_-|^2\mathcal{D}[\hat{\tau}_-]\hat{\tilde{\rho}} + |\tilde{\chi}_+|^2\mathcal{D}[\hat{\tau}_+]\hat{\tilde{\rho}}\right).$$

$$\hat{\tilde{\rho}} = \hat{U}_{sp}^\dagger\hat{U}_d^\dagger\hat{\rho}\hat{U}_d\hat{U}_{sp}$$

$$\begin{cases} \Gamma_{\mathrm{SP}_\uparrow\to\mathrm{SP}_\downarrow} = \dfrac{|\tilde{\chi}_-|^2}{2\eta}\kappa\cos^2\theta_{\mathrm{SP}}, \\[2ex] \Gamma_{\mathrm{SP}_\downarrow\to\mathrm{SP}_\uparrow} = \dfrac{|\tilde{\chi}_+|^2}{2\eta}\kappa\cos^2\theta_{\mathrm{SP}}, \end{cases}$$



$$\mathrm{SP}_\downarrow \rightleftarrows \mathrm{SP}_\uparrow \longrightarrow \mathrm{NP}_\uparrow$$

$$\Gamma_{\mathrm{SP}_\downarrow\to\mathrm{NP}_\uparrow} \simeq \frac{|\tilde{\chi}_+|^2}{2\eta}\kappa\cos^2\theta_{\mathrm{SP}}.$$

$$\mathrm{NP}_\uparrow \rightleftarrows \mathrm{NP}_\downarrow \longrightarrow \mathrm{SP}_\downarrow$$

$$\Gamma_{\mathrm{NP}_\uparrow\to\mathrm{SP}_\downarrow} \simeq \frac{\tilde{\lambda}_-^2}{2\eta}\kappa.$$

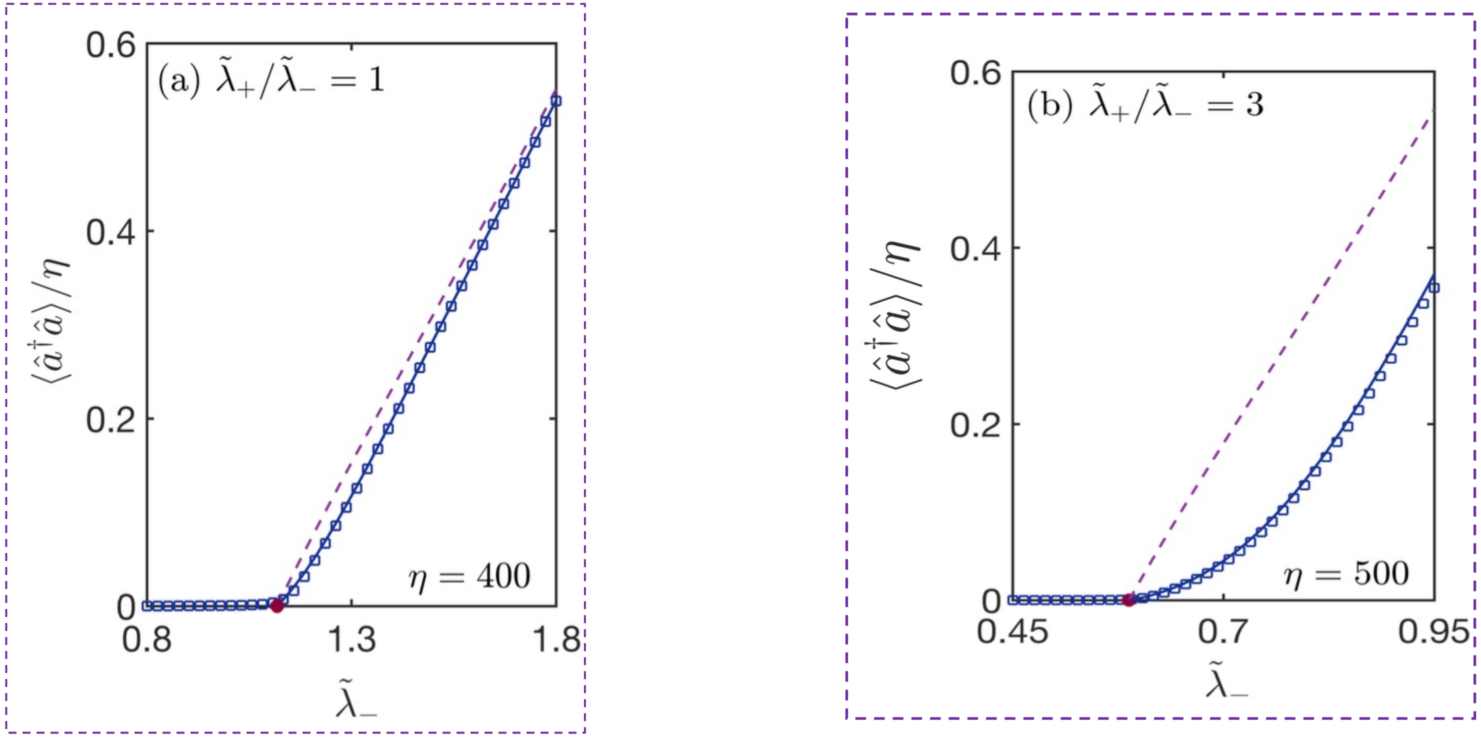
$$P_{\mathrm{SP}_\downarrow} = \frac{\tilde{\lambda}_-^2}{\tilde{\lambda}_-^2 + |\tilde{\chi}_+|^2\cos^2\theta_{\mathrm{SP}}}, \quad \langle\hat{a}^\dagger\hat{a}\rangle = P_{\mathrm{SP}_\downarrow}|c|^2\eta,$$

C. Finite η effects ---- effective master equation

Our work

SP: $\langle \hat{a}^\dagger \hat{a} \rangle = P_{\mathrm{SP}_\downarrow} |c|^2 \eta,$ $\quad P_{\mathrm{SP}_\downarrow} = \dfrac{\tilde{\lambda}_-^2}{\tilde{\lambda}_-^2 + |\tilde{\chi}_+|^2 \cos^2\theta_{\mathrm{SP}}},$ $\longrightarrow$ $P_{\mathrm{SP}_\downarrow} \simeq \left(1 + \lambda_+^2/\lambda_-^2\right)^{-1}$

controlled by $\lambda_\pm$ or r



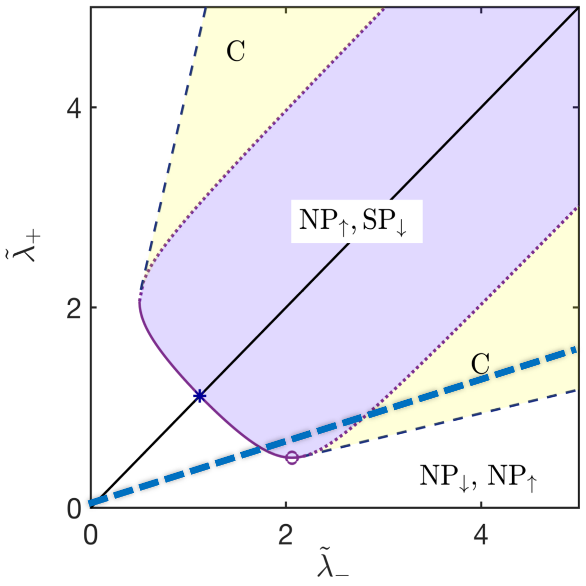
- larger value of $r = \dfrac{\lambda_+}{\lambda_-}$ leads to a more dramatic reduction of photon number

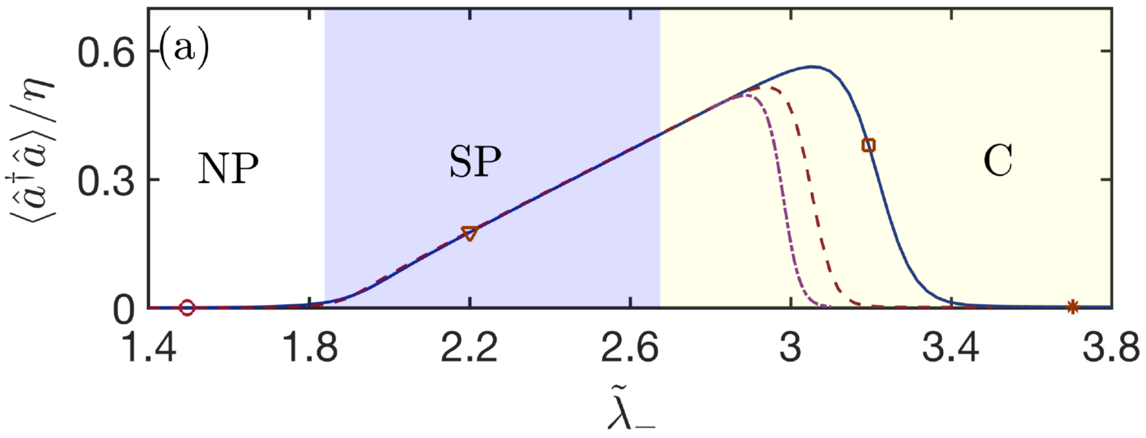
C. Finite η effects ---- First order phase transition

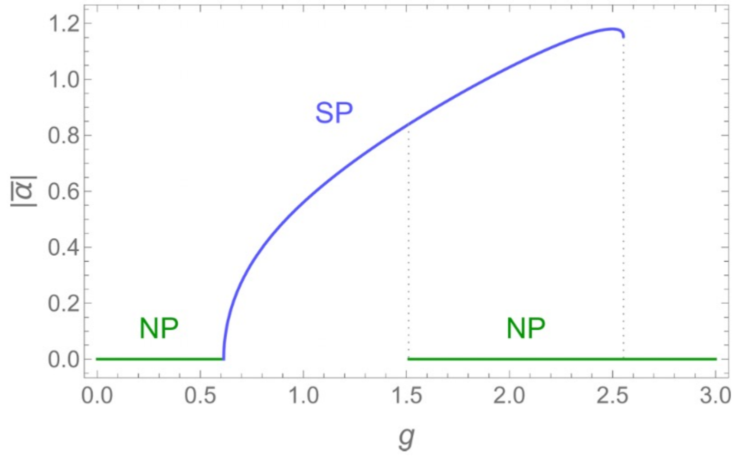
Our work

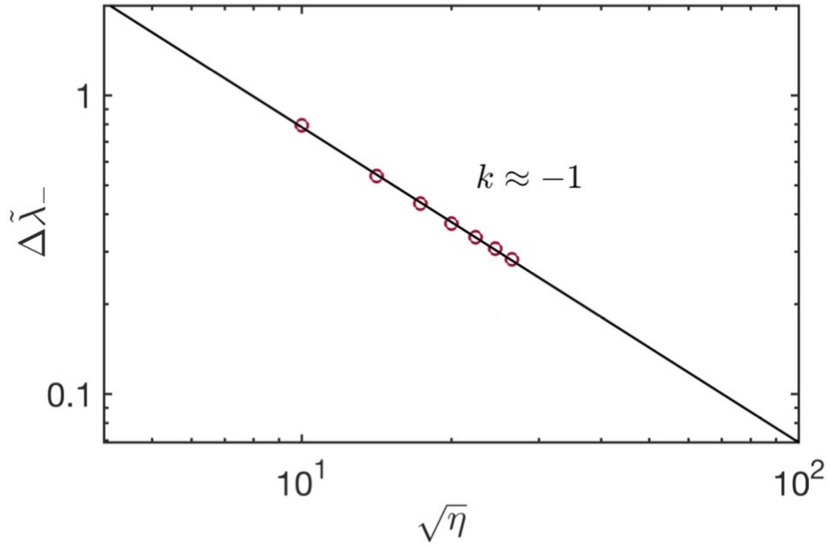
Coexistence Phase C

(numerical results)









$$\Delta\tilde{\lambda}_- = \tilde{\lambda}^*_- - \tilde{\lambda}^+_c$$

Sudden drop to zero

First order phase transition?

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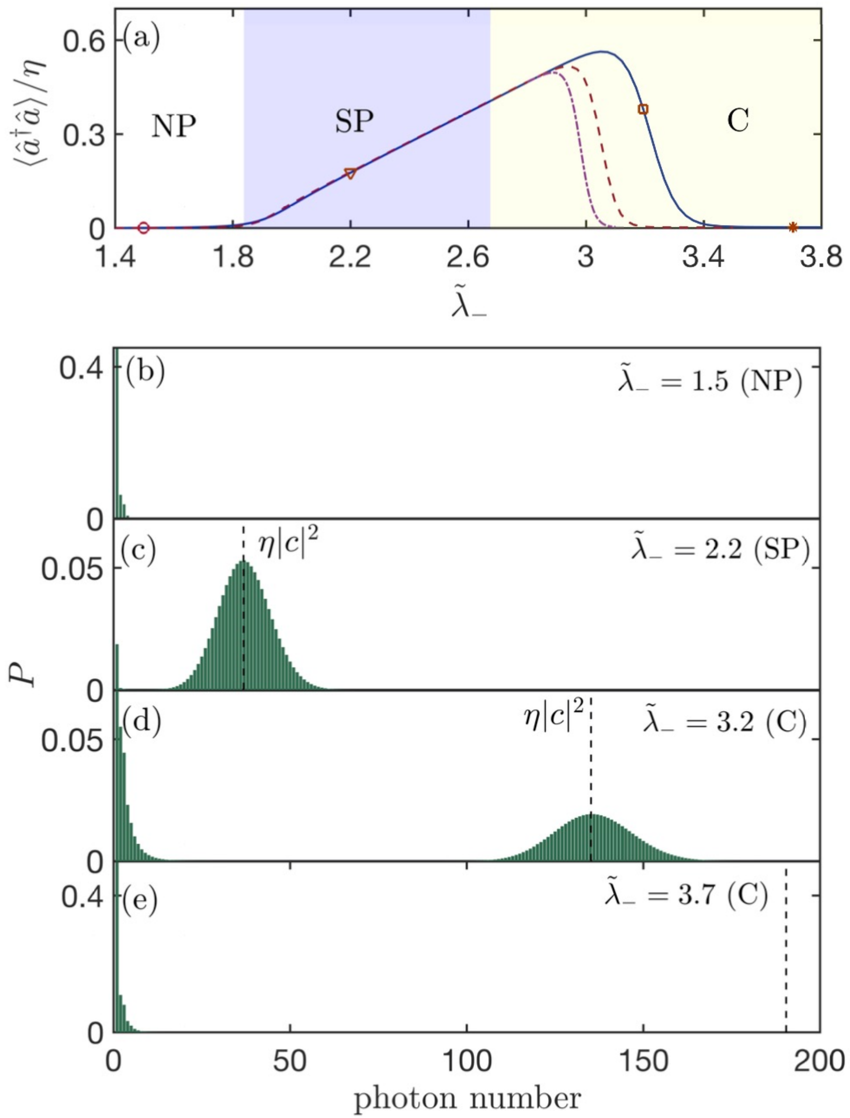
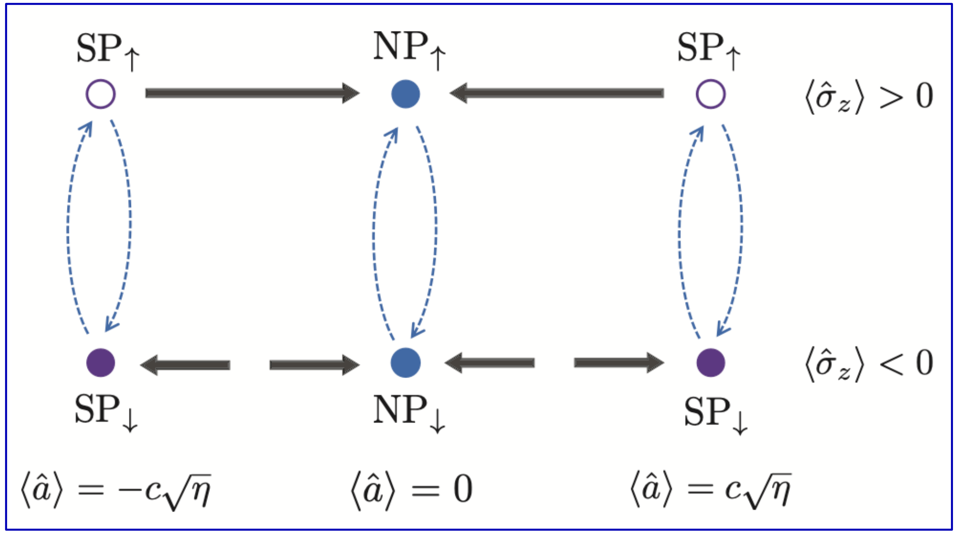
C. Finite η effects ---- First order phase transition

Coexistence Phase C



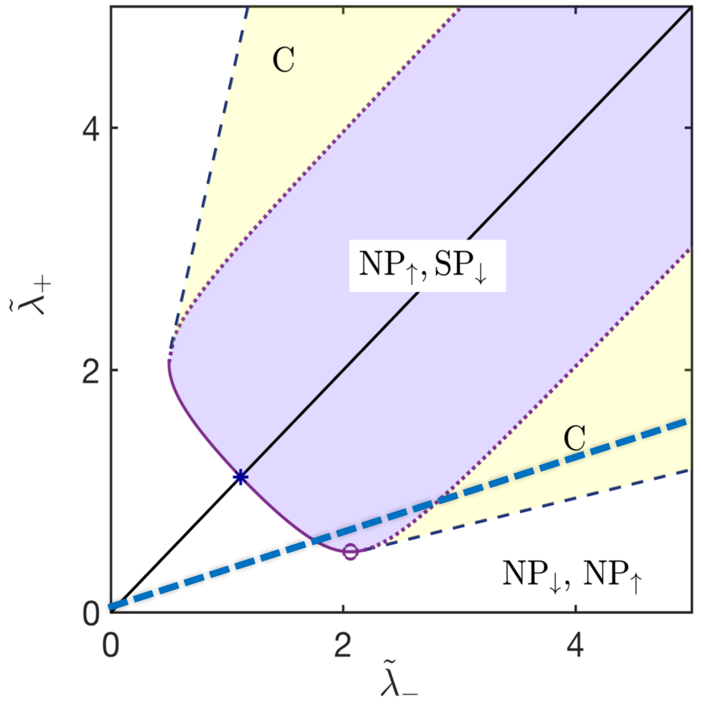


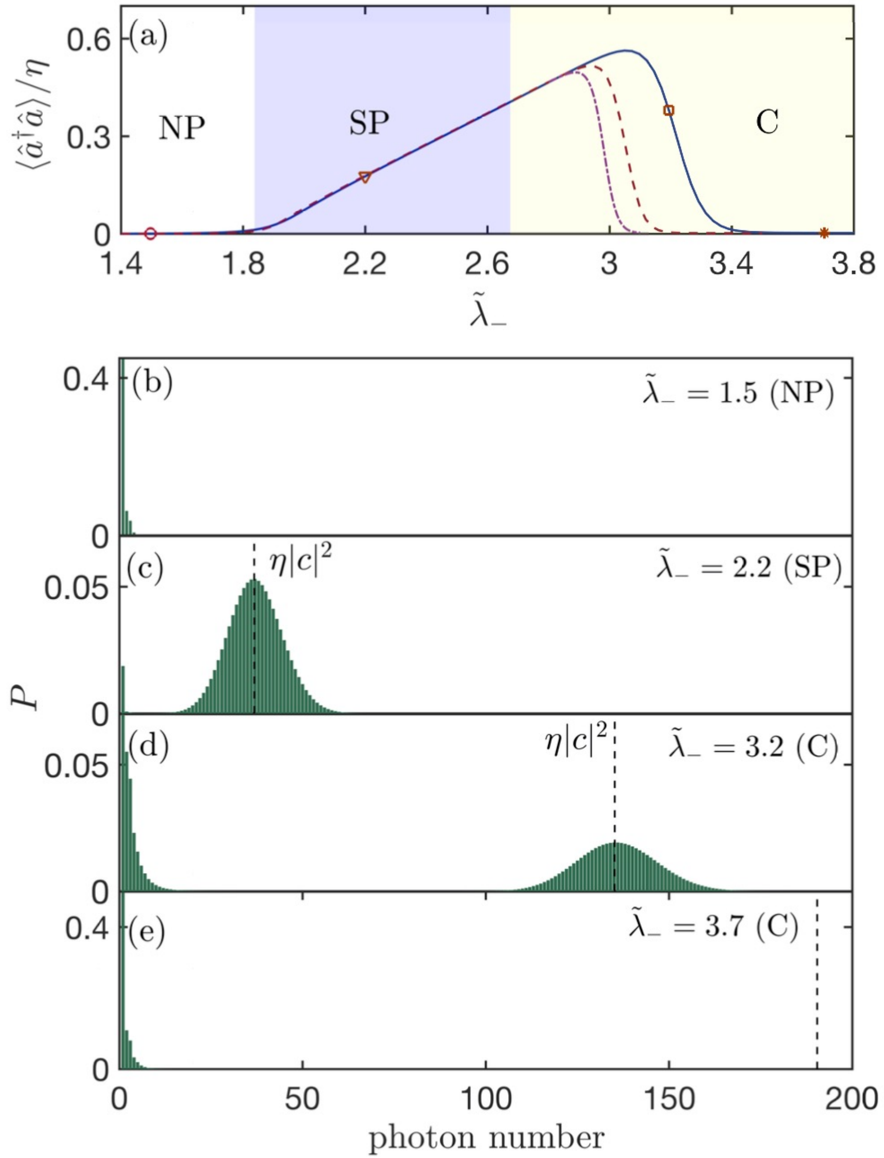
In the C region
the system is "trapped" in the NP phase

C. Finite η effects ---- First order phase transition

Our work

Coexistence Phase C (numerical results)



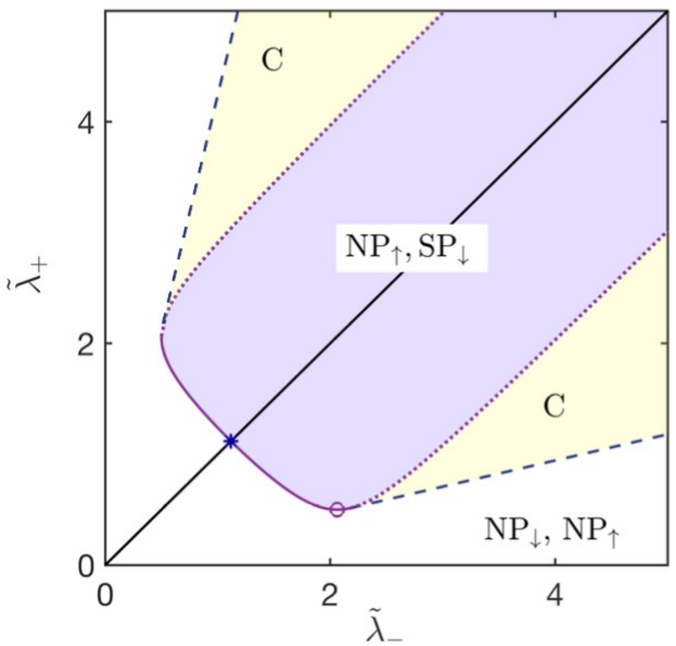


C. Finite η effects

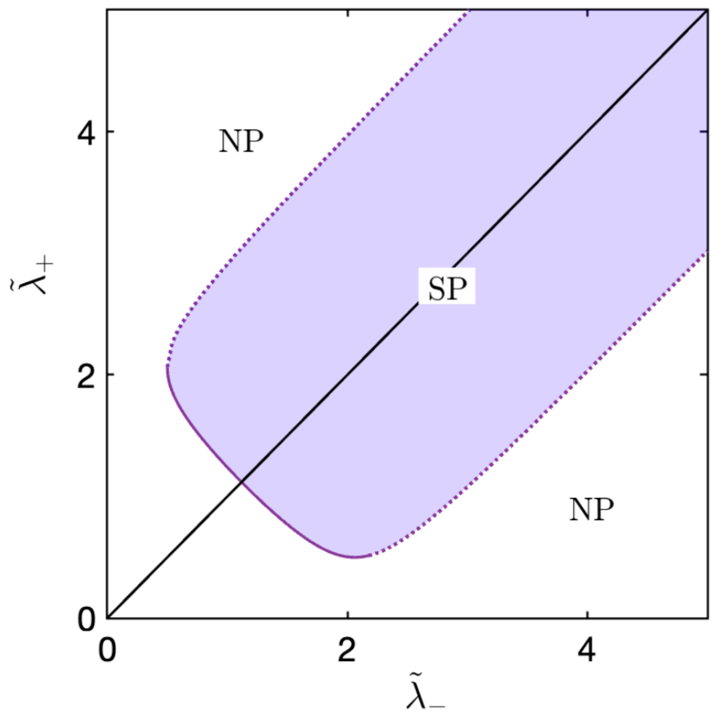
Mean-field (MF) approach ($\eta \to \infty$):

Master equation (ME): $\dot{\rho} = -i[H, \rho] + \kappa \mathcal{D}[a]$

$\eta \to \infty$ before $t \to \infty$

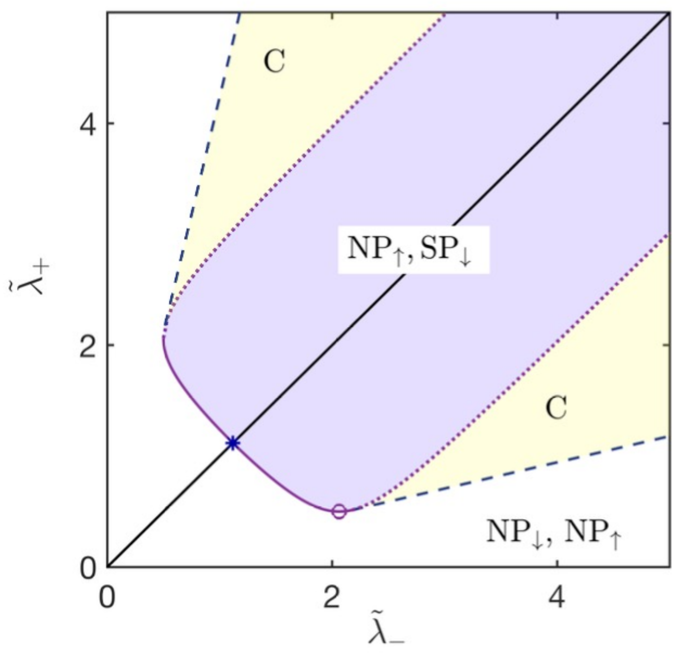


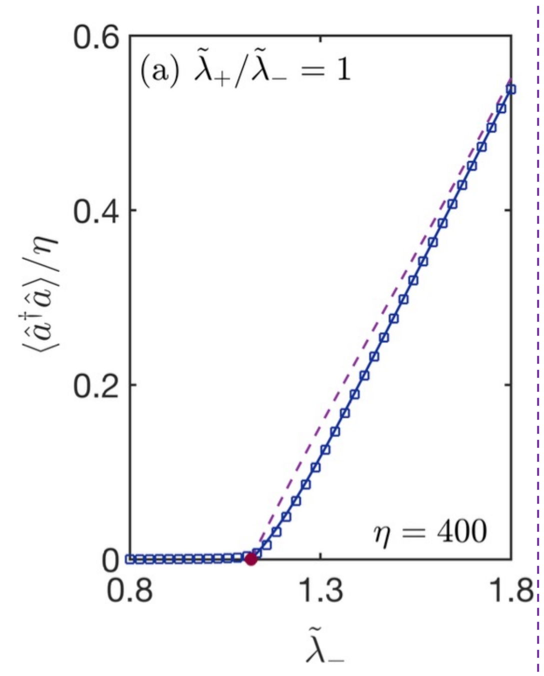
$t \to \infty$ before $\eta \to \infty$



Dissipative quantum phase transition of Rabi model

D. Scaling analysis at the second-order phase transition





D. Effective equilibrium theory

Philipp Strack
PRA ***87***, *023831 (2013)*

Dicke model: $H = \omega_0 \hat{a}^\dagger \hat{a} + \frac{\omega_z}{2} \sum_{i=1}^{N} \sigma_i^z + \frac{g}{\sqrt{N}} \sum_{i=1}^{N} \sigma_i^x \left(\hat{a}^\dagger + \hat{a}\right)$

Effective low-frequency Langevin approach and mapping to thermal ensemble

Motion equation : $\kappa \dot{x}(t) + \underbrace{\alpha^2 x(t) + \beta^3 x^3(t)}_{\text{Gives the effective potential } V(x)} = f(t).$

Gives an effective temperature

The steady-state of an equilibrium system with Landau free energy $V(x)$

can computed through the thermal average $\langle x^2 \rangle = \frac{\int dx x^2 e^{-F(x)/T_{eff}}}{\int dx e^{-F(x)/T_{eff}}}.$

D. Effective equilibrium theory

- QPT in the Dicke model *Philipp Strack, PRA87, 023831 (2013)*

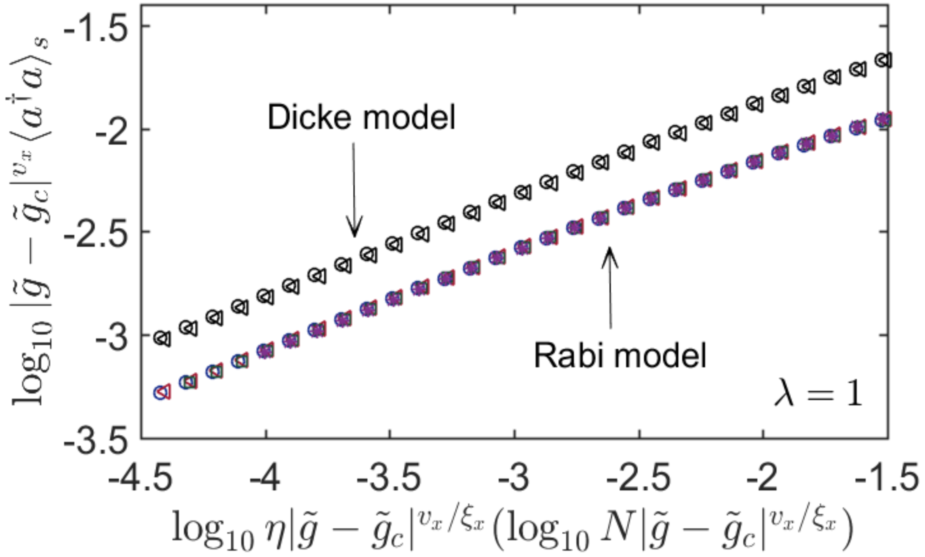
$$\langle x^2 \rangle = \sqrt{\frac{N\eta}{(\omega_0^2+\kappa^2)}}\frac{\Gamma(3/4)}{\Gamma(1/4)}$$

$N = 1$ for Rabi model ?

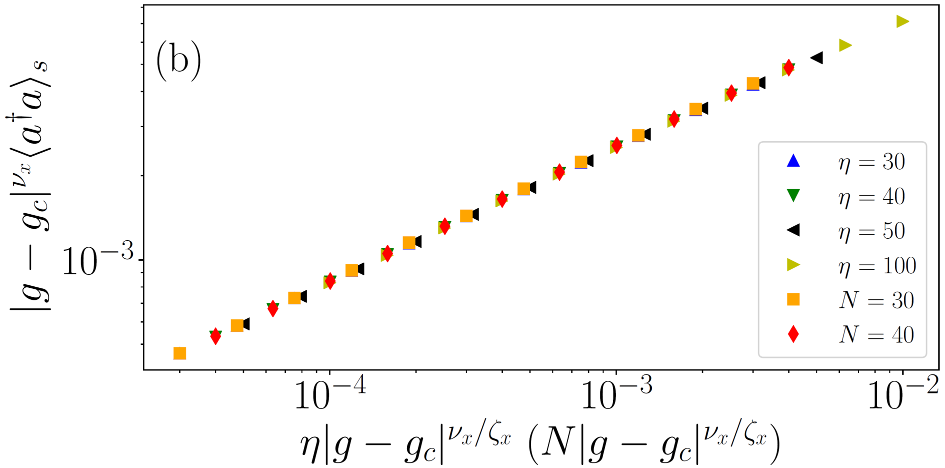
- QPT in the Rabi model *Plenio, PRA 97, 013825 (2018)*

$$|g-g_c|^{\nu_x}\langle a^\dagger a\rangle_s(N,g) = c\,F_n^{\mathrm{Dicke}}(N|g-g_c|^{\nu_x/\zeta_x})$$

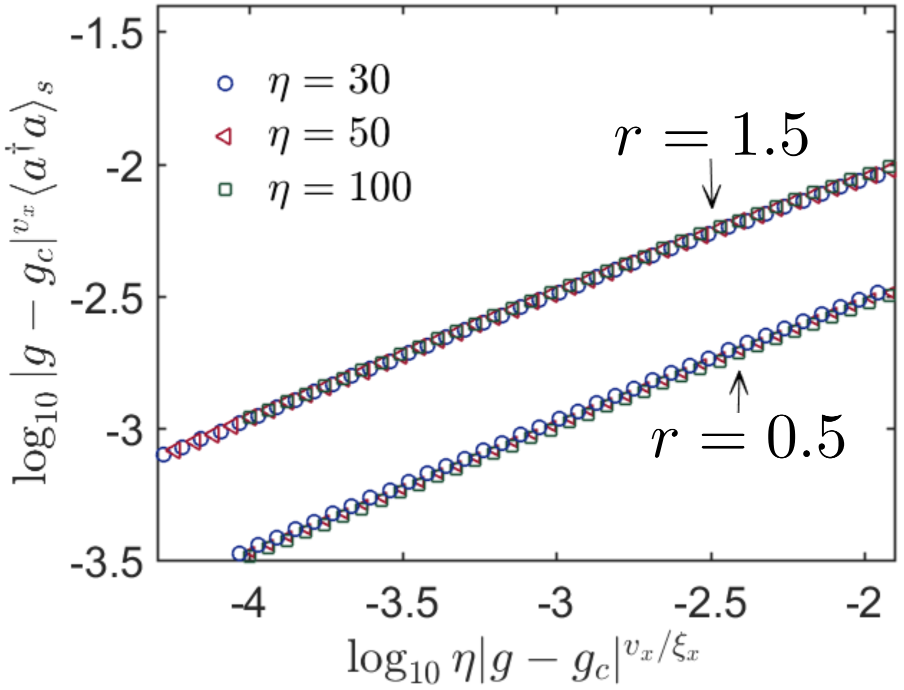
- give same exponent
- have a nonuniversal prefactor



$c \sim 0.507$



D. Effective equilibrium theory



$$|g - g_c|^{\nu_x} \langle a^\dagger a \rangle_s(\eta, g) = F_n(\eta |g - g_c|^{\nu_x/\zeta_x})$$

The scaling function affected by anisotropy.

- universality scaling function for anisotropic Rabi model ?

D. Effective equilibrium theory ---- different of Rabi model and Dicke model

$$\dot{\hat{a}} = -i\omega_0\hat{a} - \kappa\hat{a} - \frac{ig}{\sqrt{N}}\sigma_i^x + \mathcal{F},$$

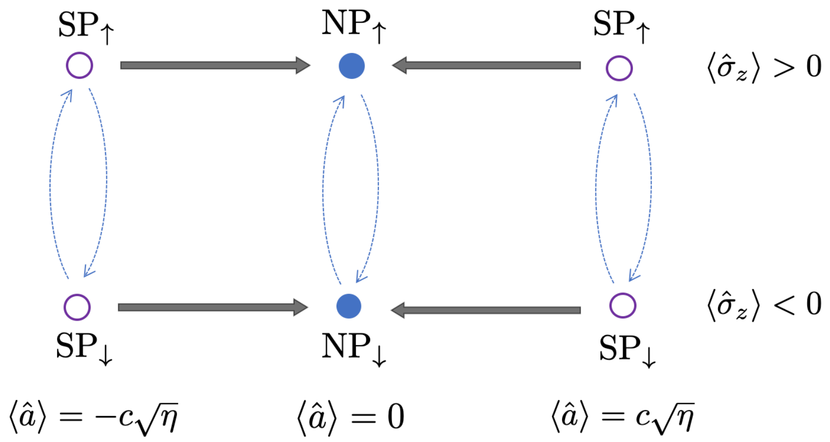
$$\dot{\sigma}_i^+ = i\omega_z\sigma_i^+ - \frac{ig}{\sqrt{N}}\sigma_i^z(\hat{a}+\hat{a}^\dagger),$$

$$\dot{\sigma}_i^z = -2\frac{ig}{\sqrt{N}}(\sigma_i^+ - \sigma_i^-)(\hat{a}+\hat{a}^\dagger).$$

Set $\hat{\sigma}_z = -1$

$$\frac{d^2\hat{x}}{dt^2} = -\omega_c^2\left(\alpha^2\hat{x} + \frac{\beta^3}{\eta}\hat{x}^3\right) - 2\kappa\frac{d\hat{x}}{dt} + \hat{\mathcal{G}}$$

Dicke model



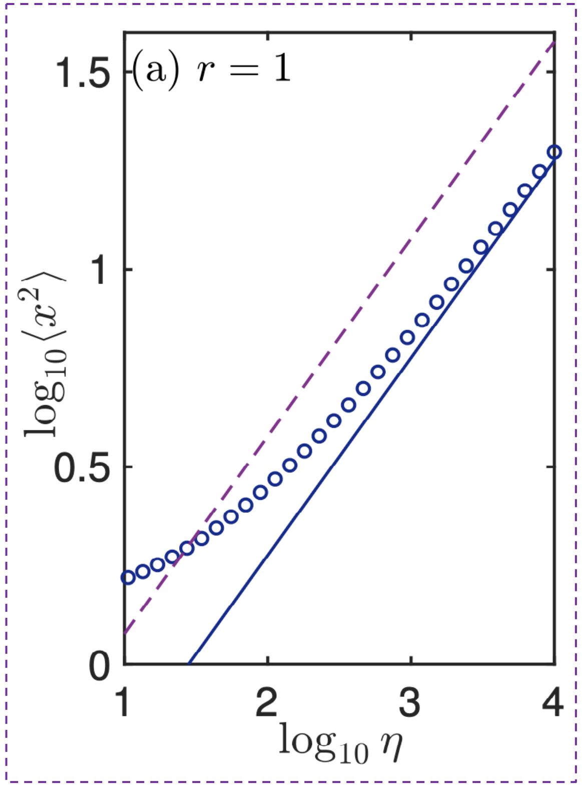
- spin flip in the Rabi model
- $\mathrm{NP}_\uparrow$ also contribute in the steady state
- Only captured steady fluctuation in the subspace $\hat{\sigma}_z = -1$

D. Effective equilibrium theory of anisotropic Rabi model

- The fluctuations in $\hat{\sigma}_z = -1$ give the steady fluctuation (at the critical point):

$$\langle x^2 \rangle = \frac{\int dx x^2 e^{-F(x)/T_{eff}}}{\int dx e^{-F(x)/T_{eff}}}.$$

- The fluctuations in $\hat{\sigma}_z = 1$ subspace do not diverge with η



Steady fluctuation (at the critical point):

$$\langle \hat{x}^2 \rangle = P_{-} \frac{\int x^2 e^{-V(x)/T} dx}{\int e^{-V(x)/T} dx}$$

P_{-} is the the population of $\mathrm{NP}_{\downarrow}$ state, $P_{-} = 1/(1 + r^2)$

$$\langle \hat{x}^2 \rangle = \left(\frac{2Q(0)}{1 + r^2} \sqrt{\frac{T}{\beta^3 \omega_c}} \right) \sqrt{\eta},$$

$$\langle \hat{x}^2 \rangle = \frac{Q(0)}{2} \sqrt{\frac{\eta}{1 + \kappa^2/\omega_c^2}}. \qquad (r = 1)$$

D. Effective equilibrium theory

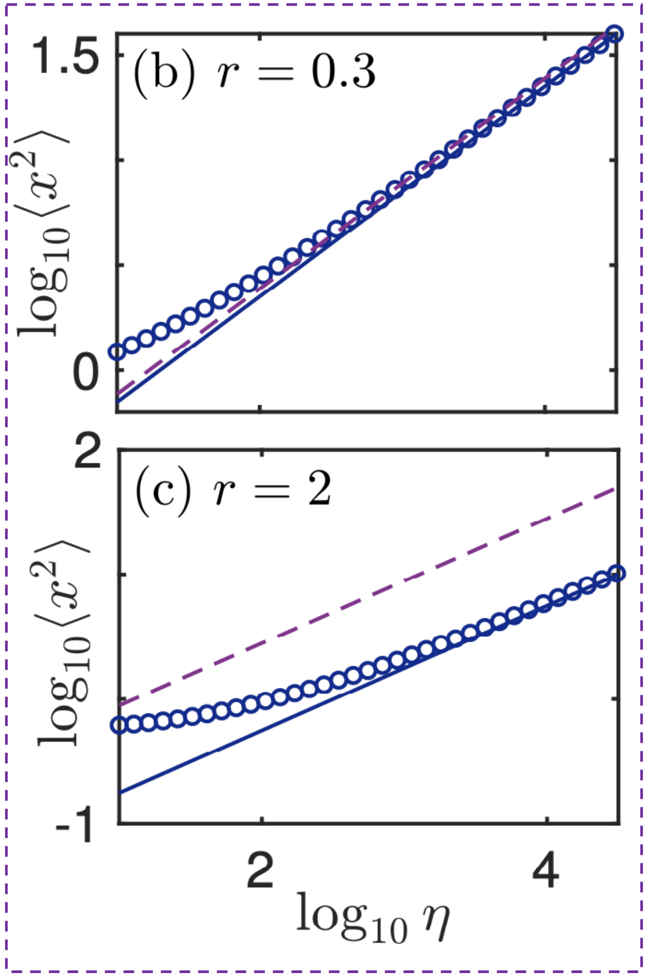
Steady fluctuation (at the critical point):

$$\langle \hat{x}^2 \rangle = \left(\frac{2Q(0)}{1+r^2} \sqrt{\frac{T}{\beta^3 \omega_c}} \right) \sqrt{\eta},$$

- the difference in the scaling behavior of the Dicke and Rabi models increases as r increases.

- finite anisotropy is not expected to modify the universality class of the model.

$$r = \lambda_+ / \lambda_-$$



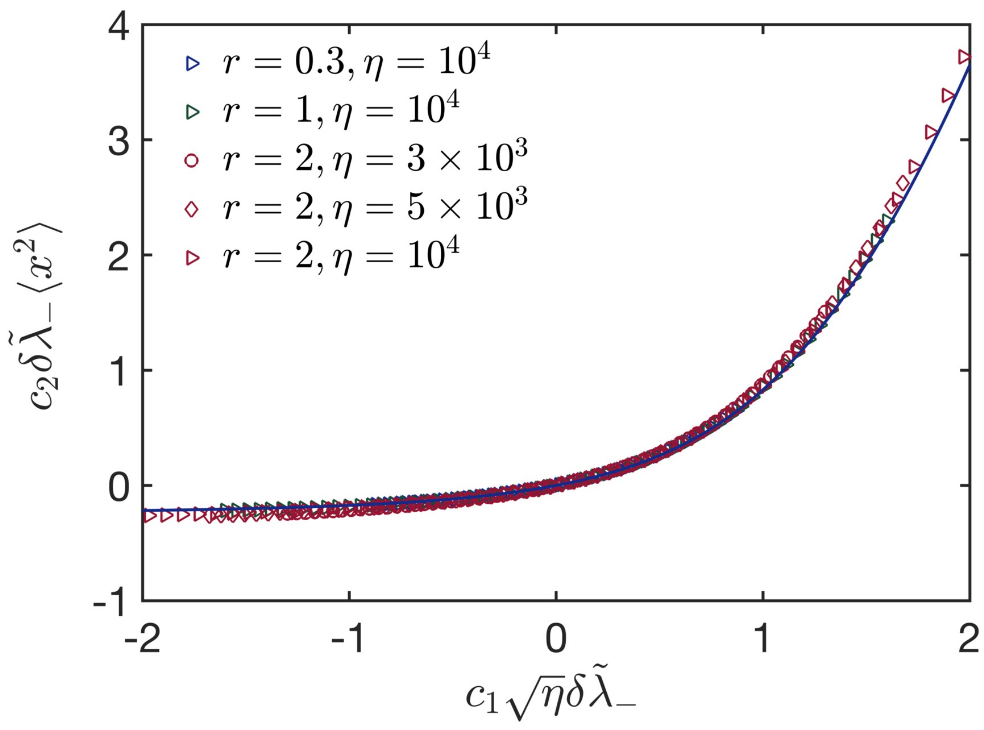
D. scaling analysis at finite η ---- universality

Non-equilibrium scaling function : $(\delta\tilde{\lambda}_-)^{\nu}\langle\hat{x}^2\rangle = F\left(\eta(\delta\tilde{\lambda}_-)^{\nu/\zeta}\right)$,

$$F(x) = (c_1/c_2)\sqrt{x}Q(c_1\sqrt{x})$$

$$c_1 = \frac{\Lambda}{2}\sqrt{\frac{\omega_c}{\beta^3 T}}, \qquad c_2 = \frac{\Lambda\omega_c}{4P_- T},$$

$$P_- = 1/(1+r^2)$$



open anisotropic QRM systems belong to the *same universality class*.

03

Dissipative quantum phase transition of Rabi model

A. Background and motivation

B. Mean-field analysis

C. Finite η effect on DQPT – beyond mean-field treatment

D. Scaling analysis at the second-order phase transition

E. Conclusion

D. Conclusion

- We studied the dissipative quantum phase transition (DQPT) in the anisotropic quantum Rabi model (AQRM) by mean-field theory.
    - phase diagram; two types of phase transition.
- We explored the finite η effect in the DQPT of AQRM by cumulant expansion and effective master equation.
    - statistical mixture of mean-field solutions;
    - suppression of superradiance ;
    - “collapse” of superradiance in the tricritical phase
- We calculated non-equilibrium scaling function at finite η, determined the universality class that the AQRM belong to.
    - non-universal factors have simple physical meaning

Thank you for your attention !