COOLING AND SQUEEZING IN PULSED OPTOMECHANICS

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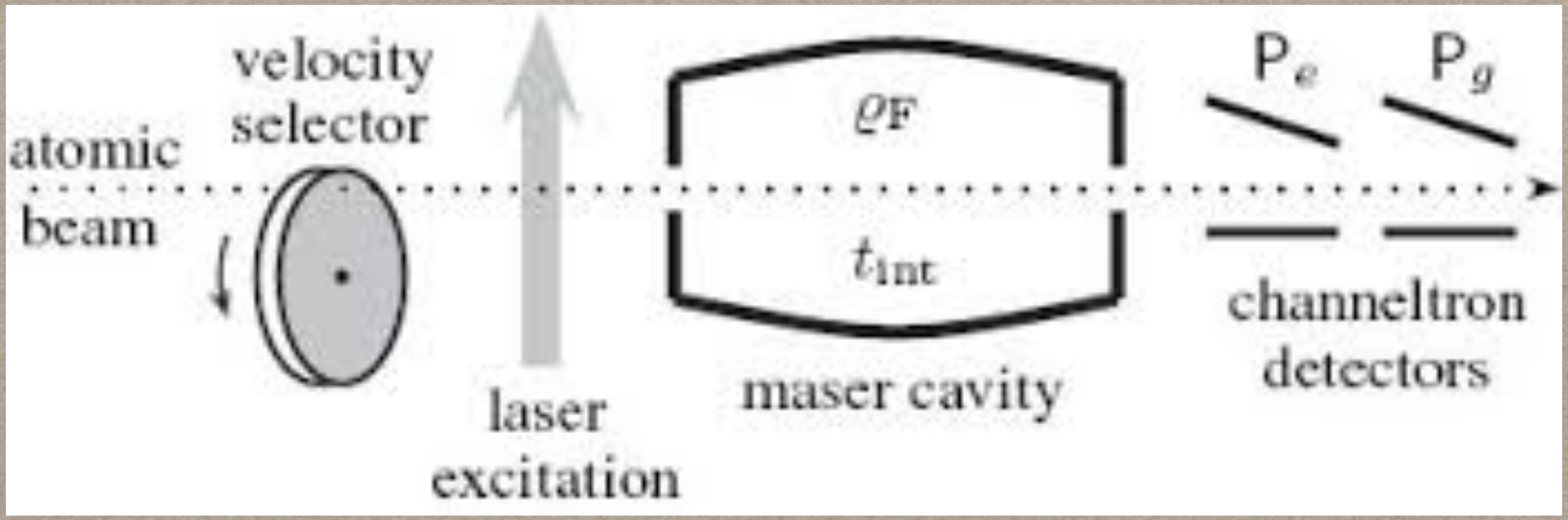
MOTIVATIONS

driving a quantum system
and engineer its irreversible dynamics
by a periodic driving

example: the micromaser

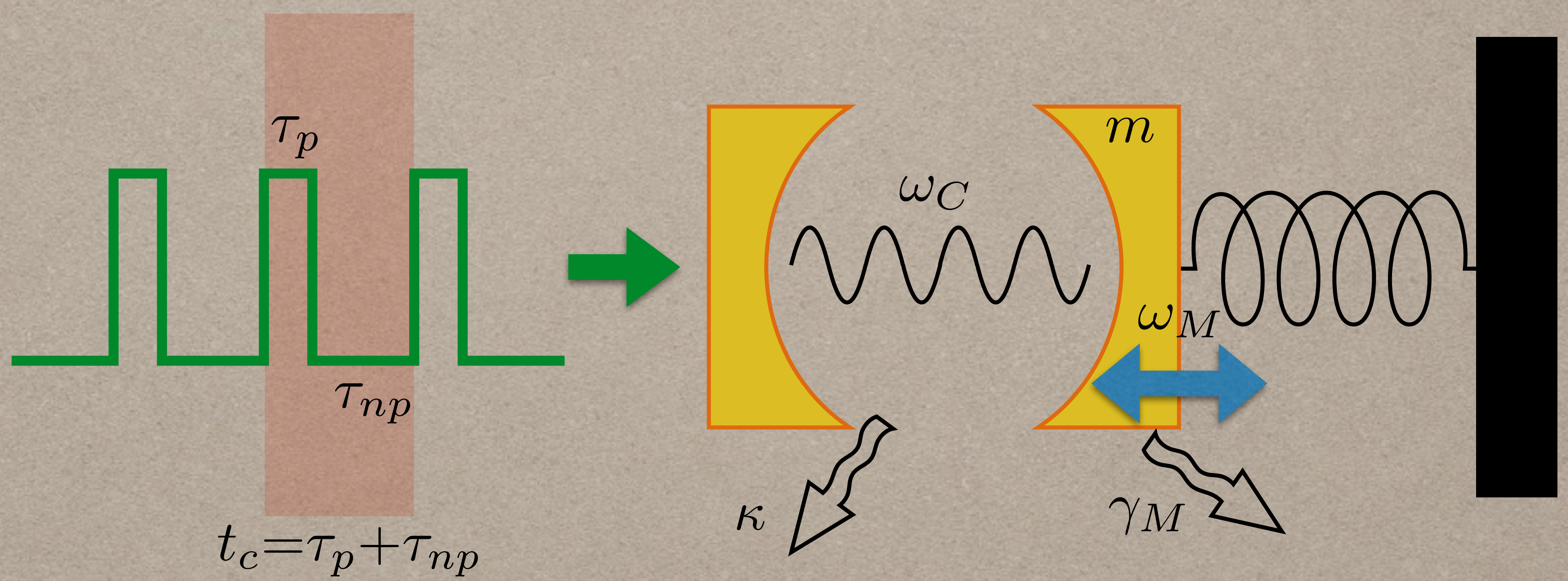


OUTLINE

- the setup: an optomechancal cavity pumped by a pulsed laser
- the Langevin equation of motion
- dynamics of the mean values
- dynamics of the fluctuations
- cooling, squeezing and entanglement

NB this is a report on preliminary results!

THE SETUP



an optomechanical cavity pumped by a pulsed laser. both the cavity mode and the cavity mirror are dissipatively coupled to their respective environments

THE HAMILTONIAN AND THE QUANTUM LANGEVIN EQUATIONS

$$\hat{H}^I_{\mathrm{p}} = \hbar\Delta\hat{a}^\dagger\hat{a} + \frac{\hbar\omega_M}{2}(\hat{q}^2 + \hat{p}^2) - \hbar G\hat{a}^\dagger\hat{a}\hat{q} + i\hbar\mathcal{E}(\hat{a}^\dagger - \hat{a})$$

$$\hat{H}^I_{\mathrm{np}} = \hbar\Delta\hat{a}^\dagger\hat{a} + \frac{\hbar\omega_M}{2}(\hat{q}^2 + \hat{p}^2) - \hbar G\hat{a}^\dagger\hat{a}\hat{q}$$

$$\Delta = \omega_O - \omega_L$$

$$t \subset \tau_{\mathrm{p}} \begin{cases} \dot{\hat{q}} = \omega_M p \\ \dot{\hat{p}} = -\omega_M q + G\hat{a}^\dagger\hat{a} - \gamma_M p + \xi \\ \dot{\hat{a}} = -i\Delta a + iGaq + \mathcal{E} - \kappa a + \sqrt{2\kappa}\hat{a}_{\mathrm{in}} \end{cases} \qquad t \subset \tau_{\mathrm{np}} \begin{cases} \dot{\hat{q}} = \omega_M p \\ \dot{\hat{p}} = -\omega_M q + G\hat{a}^\dagger\hat{a} - \gamma_M p + \xi \\ \dot{\hat{a}} = -i\Delta a + iGaq - \kappa a + \sqrt{2\kappa}\hat{a}_{\mathrm{in}} \end{cases}$$

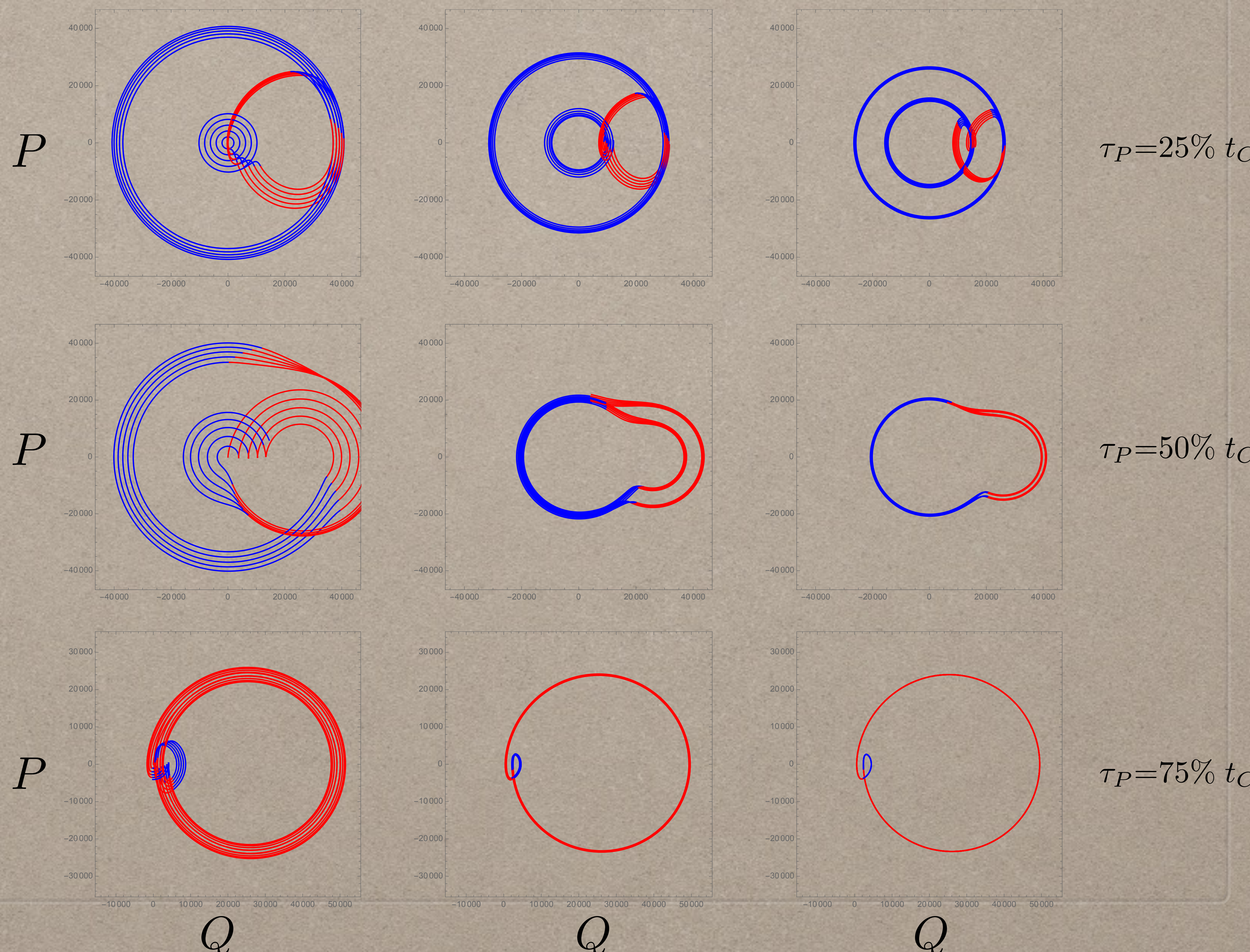
THE DYNAMICS OF THE AVERAGE VALUES

$$t \subset \tau_P \begin{cases} \dot{Q} = \omega_M P \\ \dot{P} = -\omega_M Q - \gamma_M P + \frac{G}{2}(X^2 + Y^2) \\ \dot{X} = -\kappa X + \Delta Y - GYQ + \sqrt{2}\mathcal{E} \\ \dot{Y} = -\Delta X - \kappa Y + GXQ \end{cases}$$

$$t \subset \tau_{NP} \begin{cases} \dot{Q} = \omega_M P \\ \dot{P} = -\omega_M Q - \gamma_M P + \frac{G}{2}(X^2 + Y^2) \\ \dot{X} = -\kappa X + \Delta Y - GYQ \\ \dot{Y} = -\Delta X - \kappa Y + GXQ \end{cases}$$

phase space dynamics of mirror average values as a function of time

m=150ng
$\omega_M/(2\pi)$=1MHz
$\gamma_M/(2\pi)$=100Hz
T=0.1K
$\Delta=\omega_M$
L=25mm
κ=1.34MHz
λ_L=1064nm
P_L=10mW



THE FLUCTUATIONS

linearize the fluctuations around the average $\hat{o} = O + \delta o$

since the mirror and field state is gaussian it is convenient to describe the fluctuation dynamics in term of the covariance matrix $\sigma_{ij} = \frac{1}{2}\langle \hat{u}_i(t)\hat{u}_j(t) + \hat{u}_j(t)\hat{u}_i(t)\rangle$

$$\frac{d\sigma}{dt} = S\,\sigma + \sigma\,S^{\mathrm{T}} + N$$

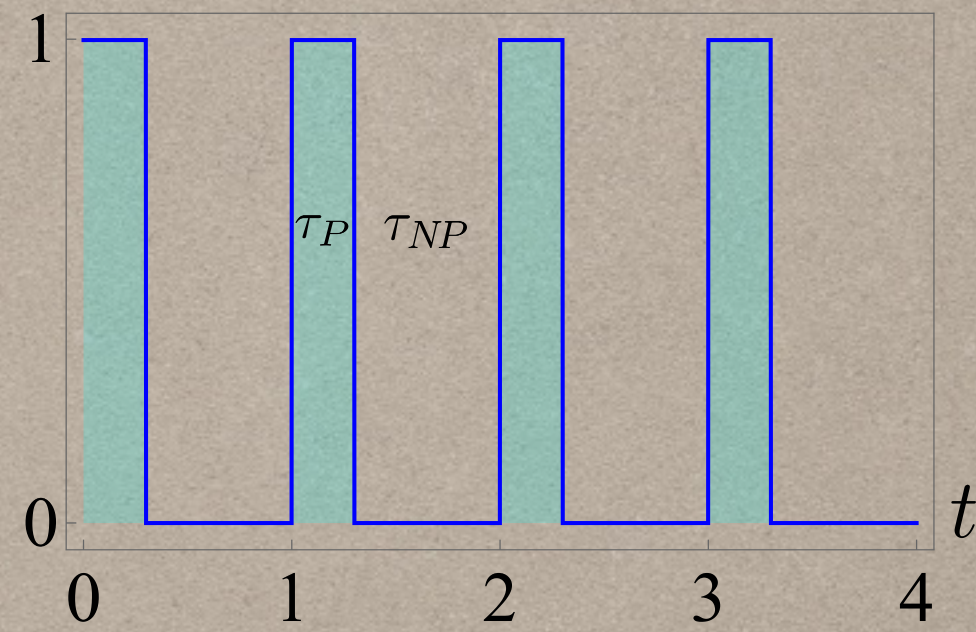
$$u = \{\delta q, \delta p, \delta x, \delta y\}$$

$$N = \{0, \gamma_M(2N_{th}+1), \kappa, \kappa\}$$

$$S = \begin{pmatrix} 0 & \omega_M & 0 & 0 \\ -\omega_M & -\gamma_M & GX & GY \\ -GY & 0 & -\kappa & -(GQ-\Delta) \\ GX & 0 & GQ-\Delta & -\kappa \end{pmatrix}$$

mirror cooling

$$t_C = \tau_P + \tau_{NP} = \frac{20}{\kappa}$$



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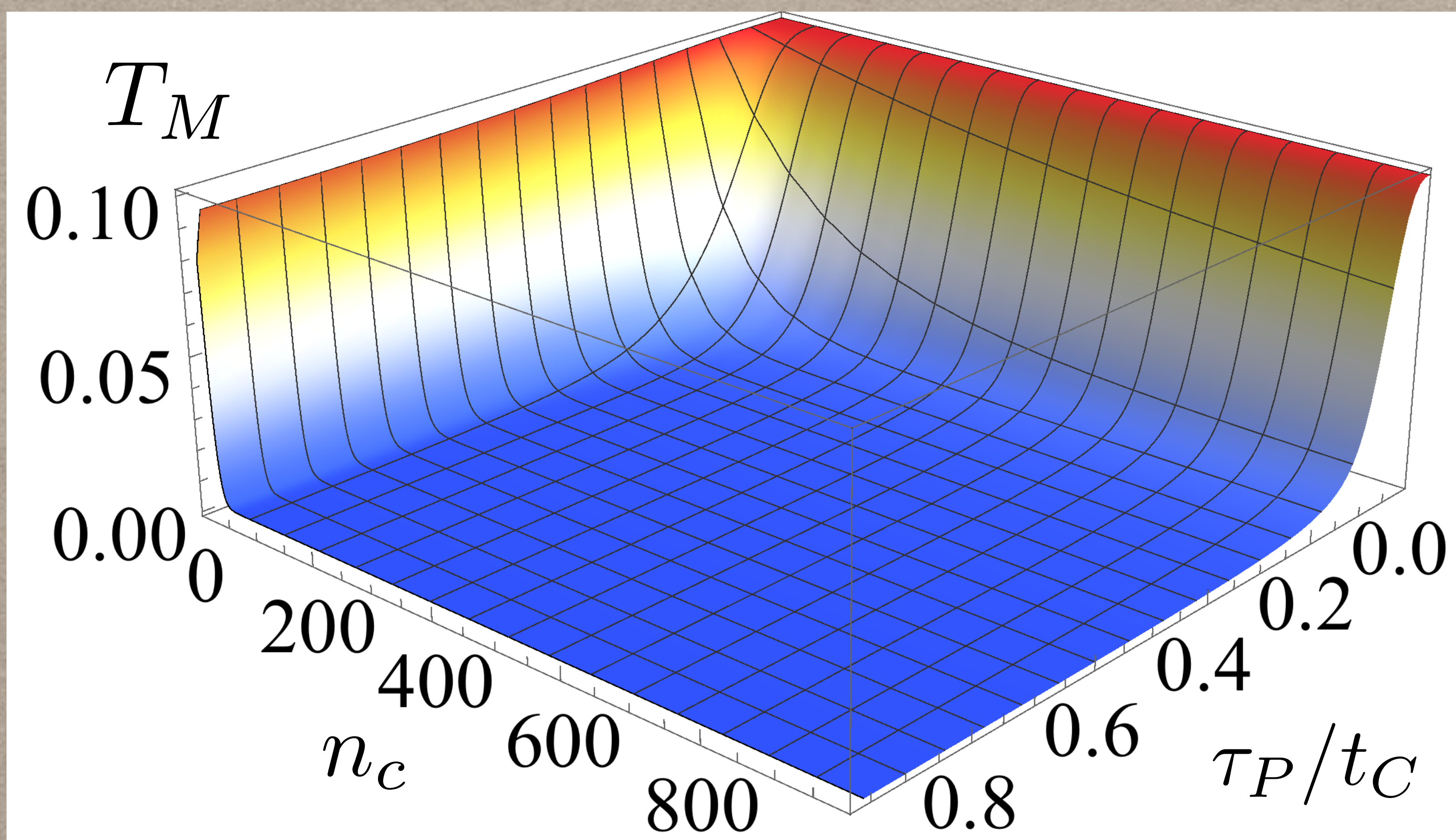
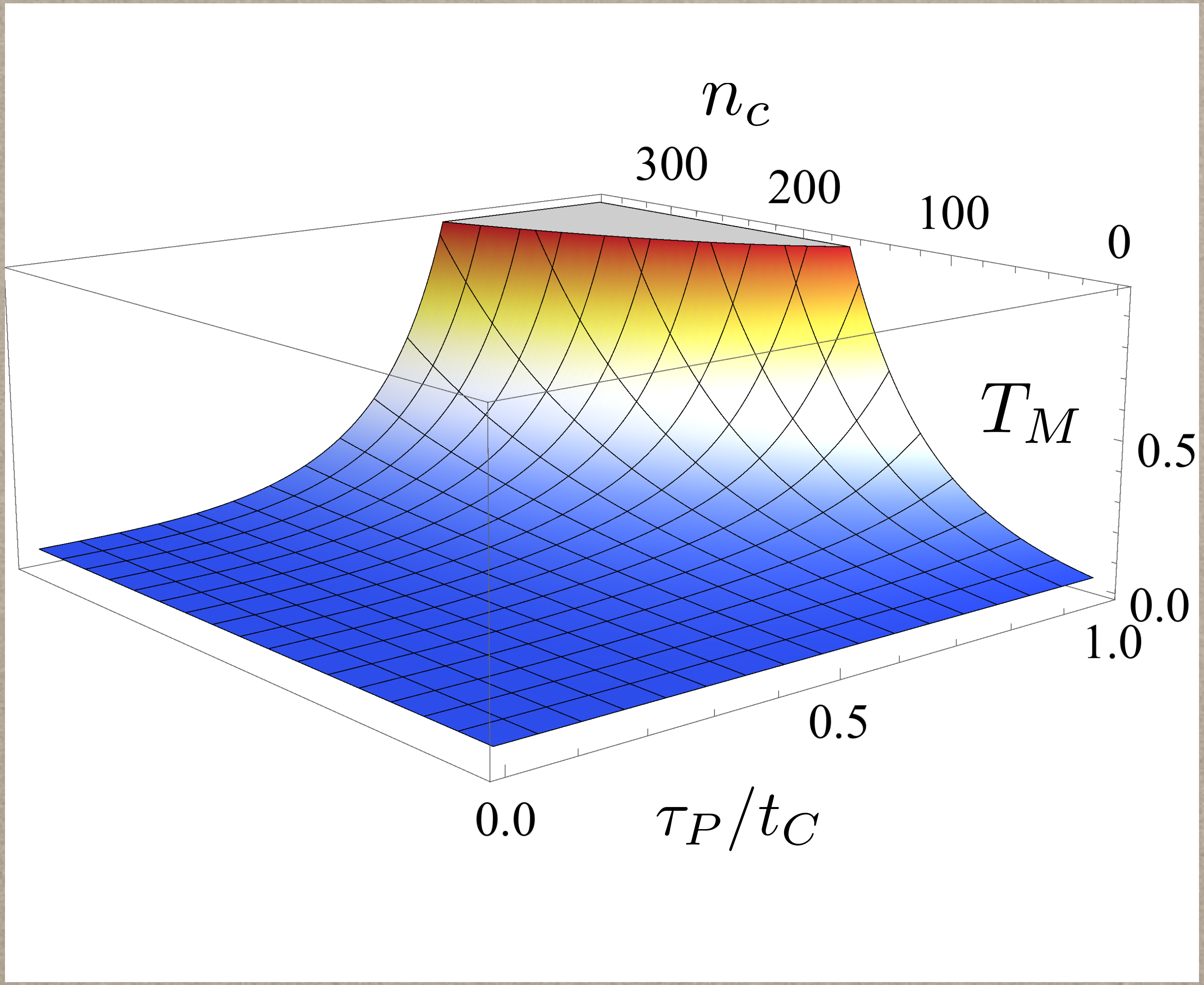


MIRROR HEATING



$$t_c = \tau_p + \tau_{np} = \frac{10}{\kappa}$$

$$\Delta = -\omega_M$$

$m = 150\text{ng}$

$\omega_M/(2\pi) = 1\text{MHz}$

$\gamma_M/(2\pi) = 100\text{Hz}$

$T = 0.1\text{K}$

$L = 25\text{mm}$

$\kappa = 1.34\text{MHz}$

$\lambda_L = 1064\text{nm}$

$P_L = 2\text{mW}$

$t_c = 10/\kappa$

mirror squeezing

$$t_C = \tau_P + \tau_{NP} = \frac{20}{\kappa}$$

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$\omega_M/(2\pi)$=1MHz
$\gamma_M/(2\pi)$=100Hz
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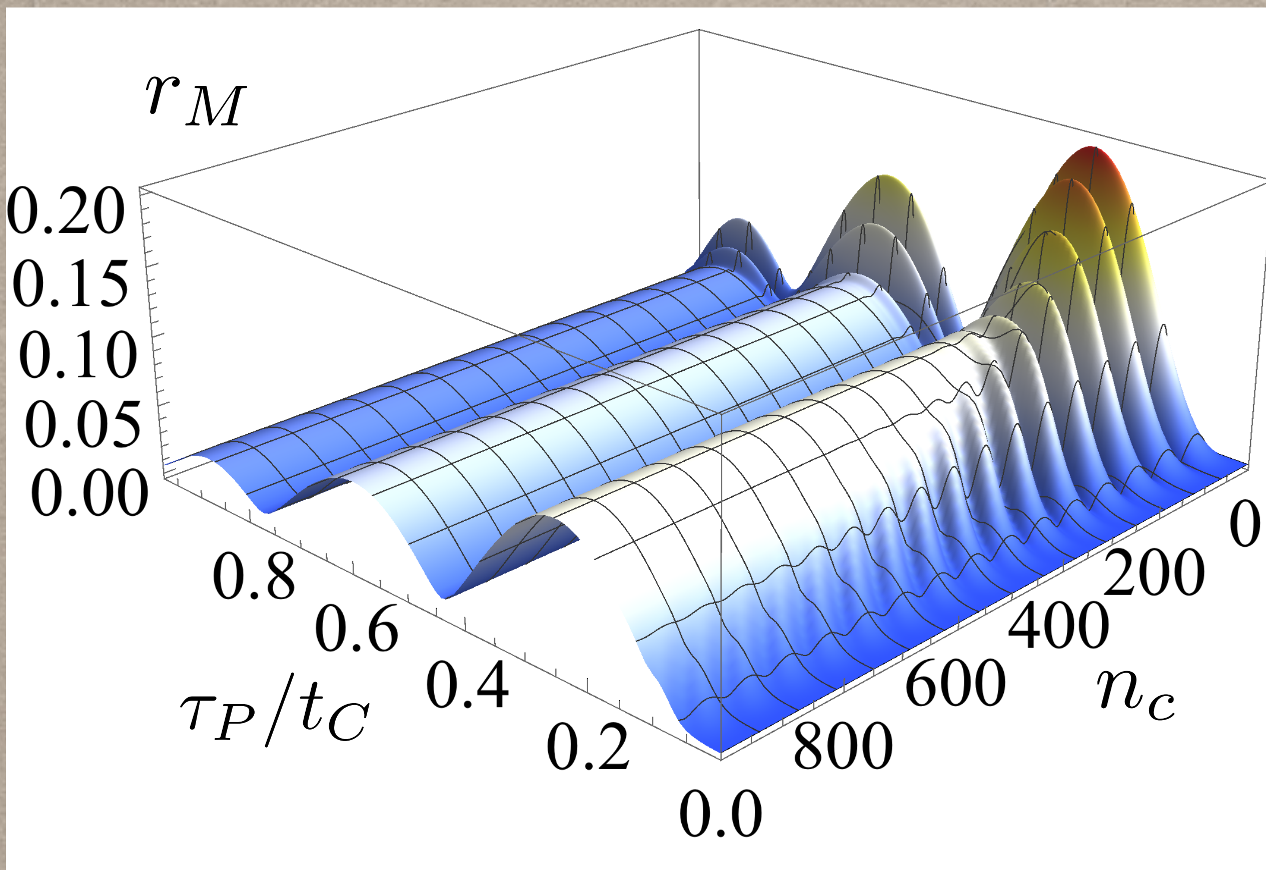
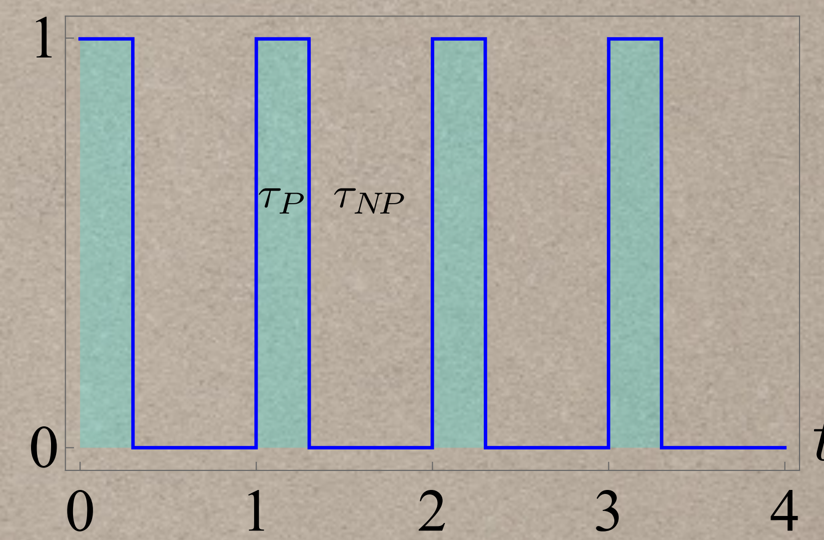
$\Delta=\omega_M$
L=25mm
κ=1.34MHz
λ_L=1064nm
P_L=10mW





$$t_c = \tau_p + \tau_{np} = \frac{10}{\kappa}$$

$$\Delta = -\omega_M$$

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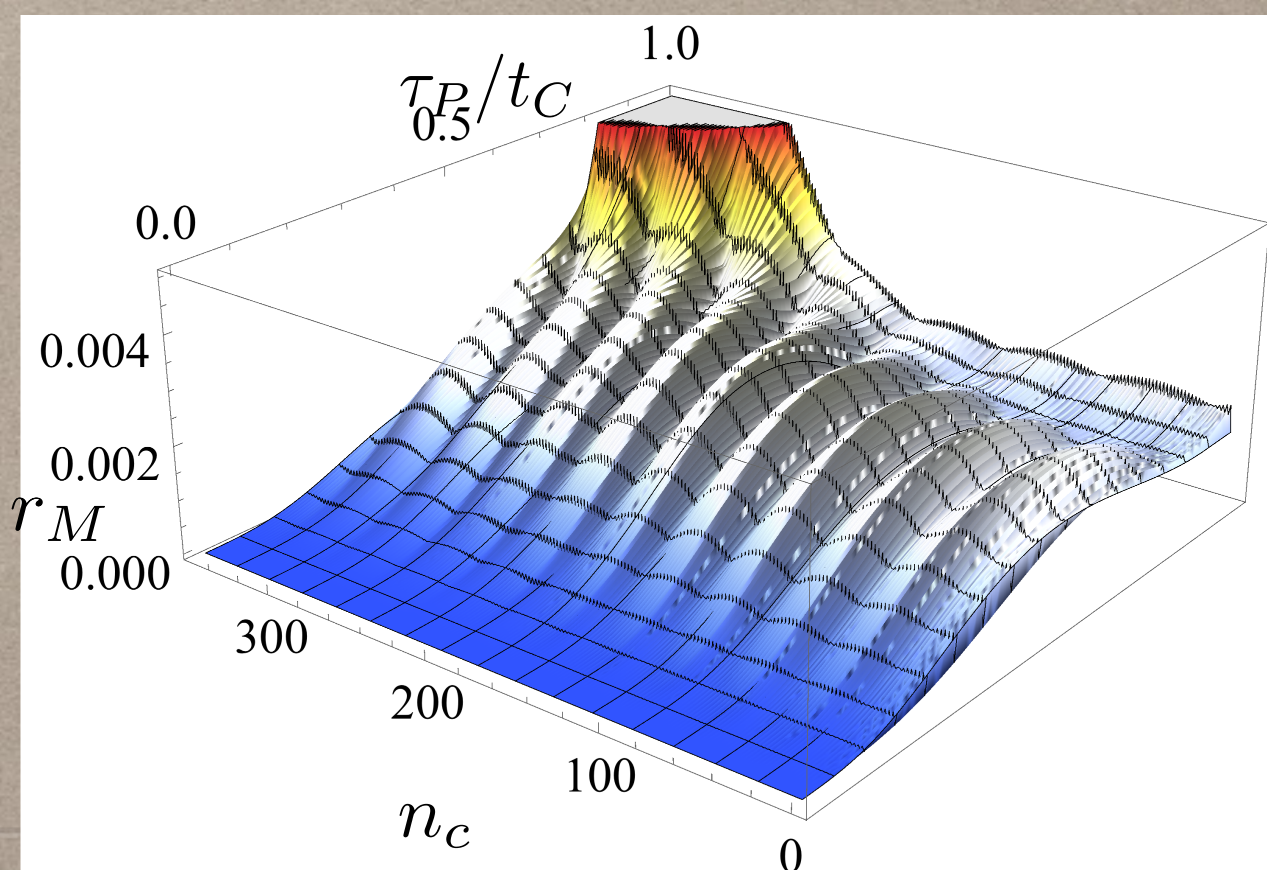
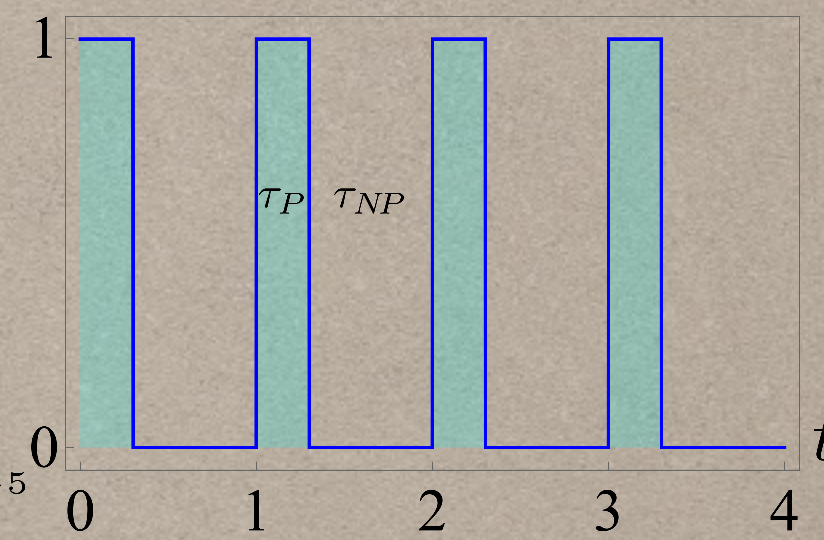
$t_c = 10/\kappa$

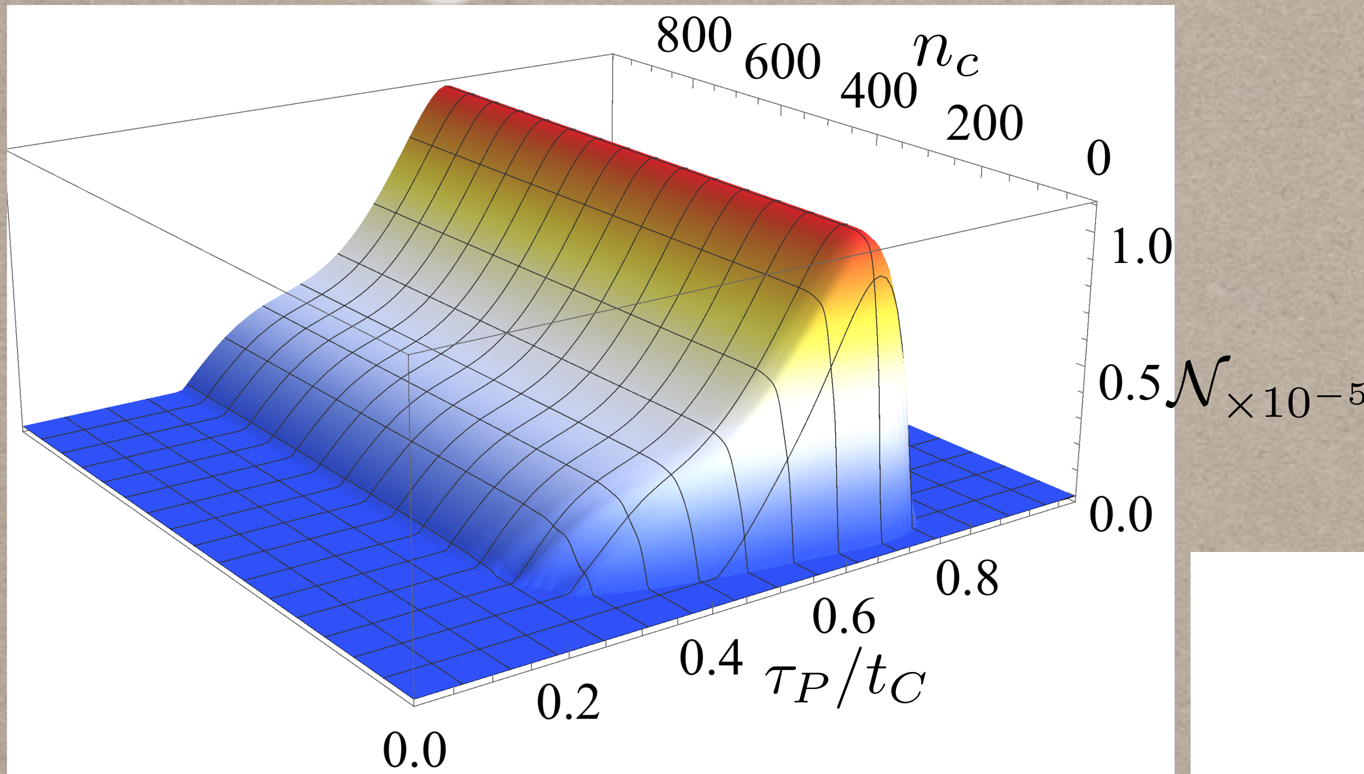


mirror field entanglement

$$t_C = \tau_P + \tau_{NP} = \frac{20}{\kappa}$$



$m = 150\text{ng}$
$\omega_M/(2\pi) = 1\text{MHz}$
$\gamma_M/(2\pi) = 100\text{Hz}$
$T = 0.1\text{K}$
$\Delta = \omega_M$
$L = 25\text{mm}$
$\kappa = 1.34\text{MHz}$
$\lambda_L = 1064\text{nm}$
$P_L = 10\text{mW}$



$$t_c = \tau_p + \tau_{np} = \frac{10}{\kappa}$$

$$\Delta = -\omega_M$$

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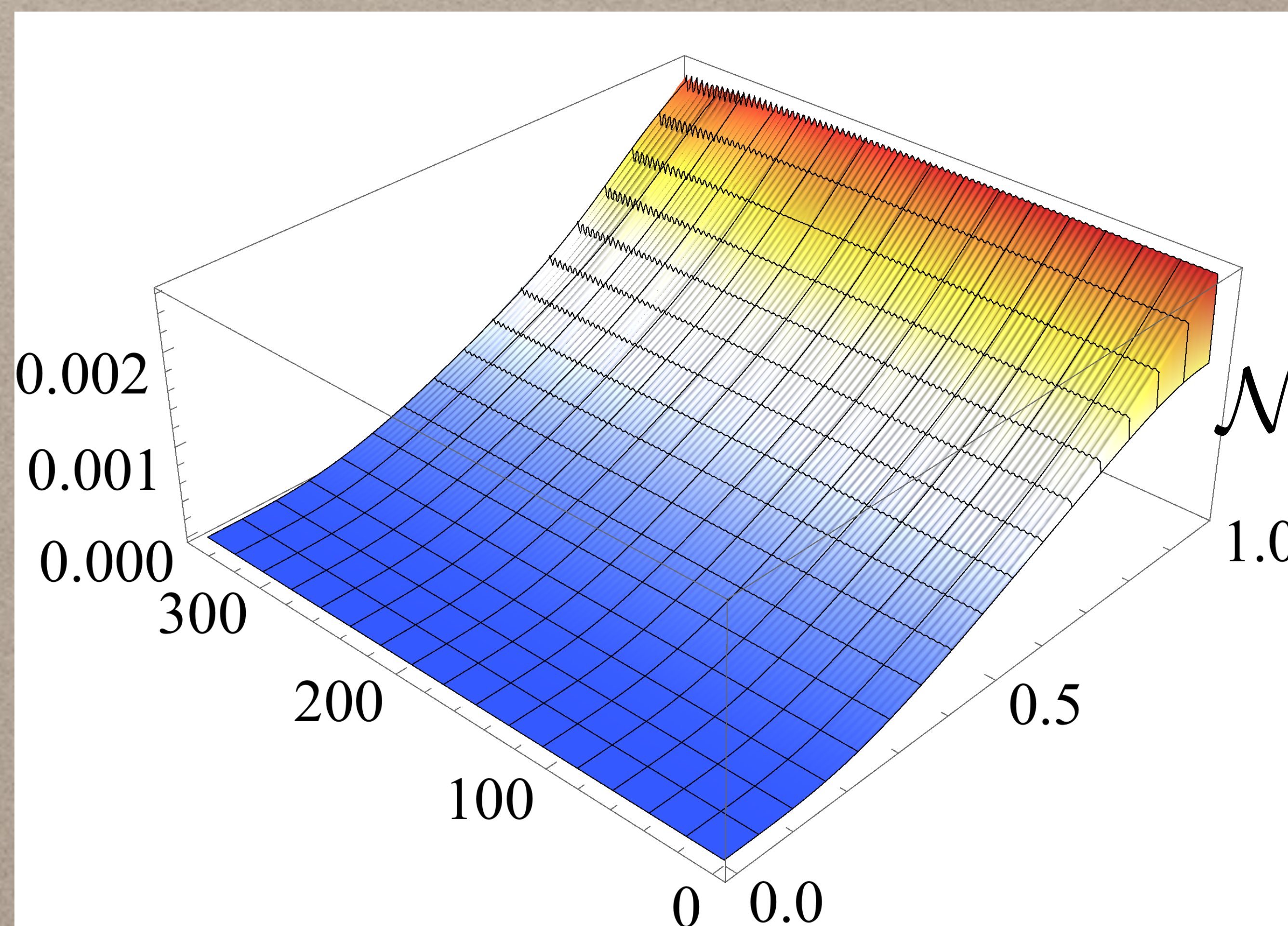
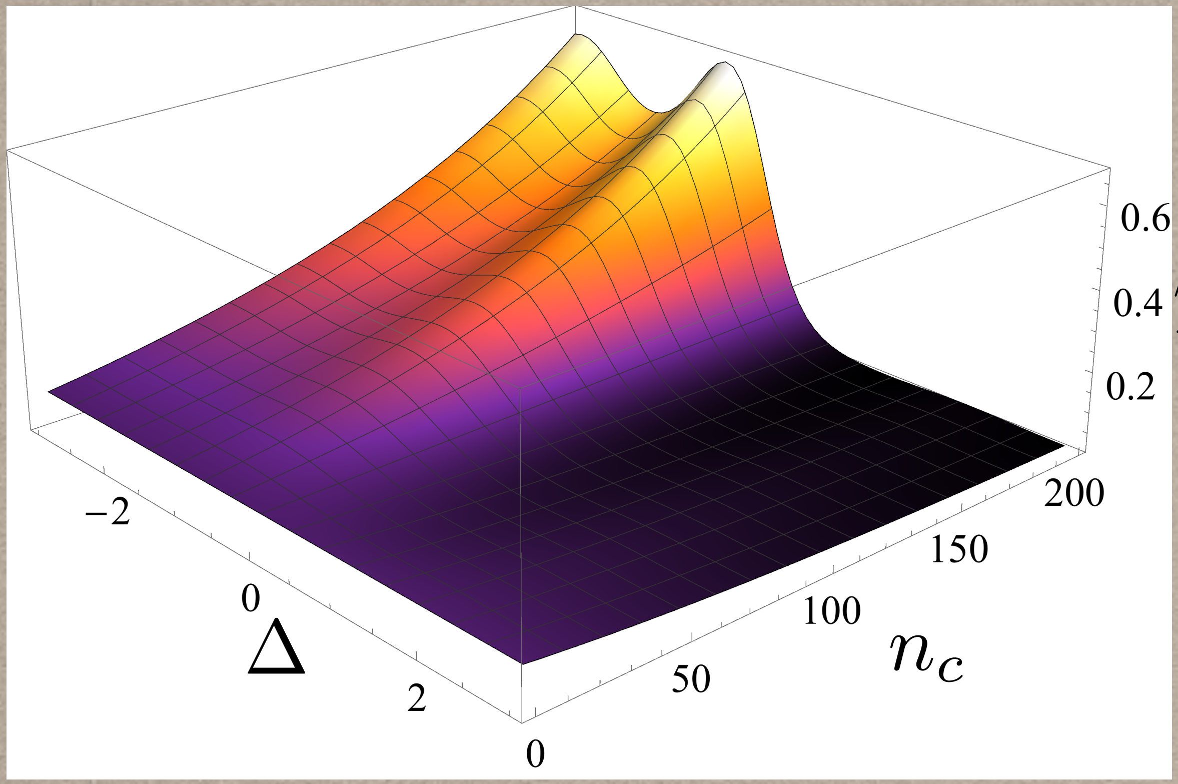
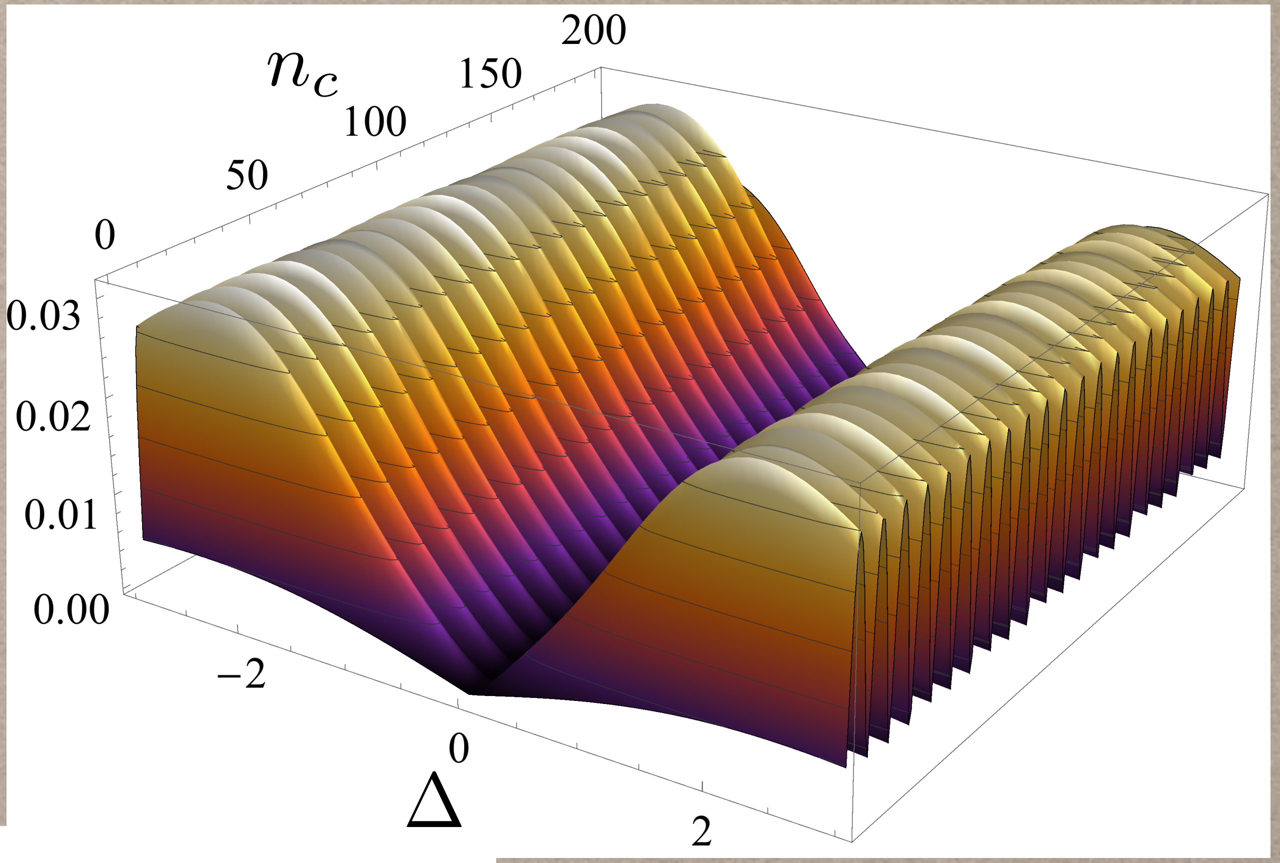
$\lambda_L = 1064\text{nm}$
$P_L = 2\text{mW}$
$t_c = 10/\kappa$



Varying the detuning Δ





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$\omega_M/(2\pi)$=1MHz

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T=0.1K

L=25mm

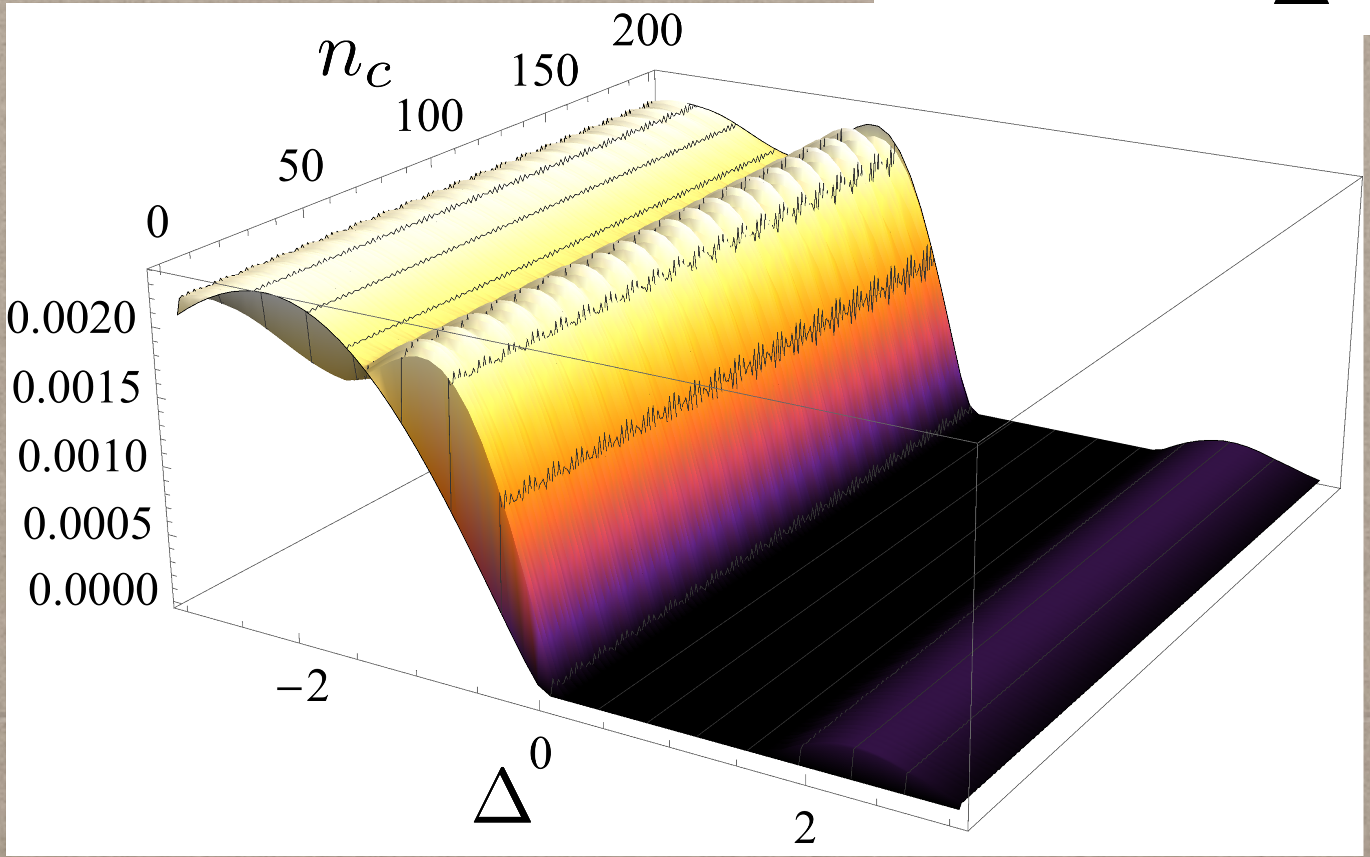
κ=1.34MHz

λ_L=1064nm

P_L=10mW

$t_c = 6/\kappa$

$\tau_P = 50\% t_c$



$$t_c = \tau_p + \tau_{np} = \frac{6}{\kappa}$$