FROM THE PARAMETRIC DOWN-CONVERSION TO THE RAMAN SCATTERING: NONLINEAR AND QUANTUM PHENOMENA IN LOSSY MEDIA

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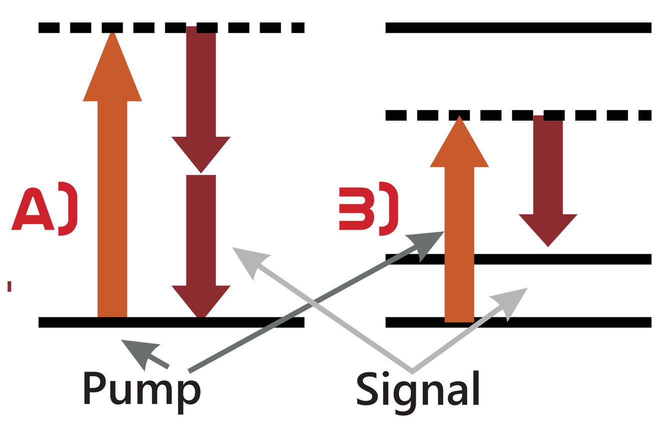
¿QUESTIONS?

- Sudden death of squeezing in lossy nonlinear media?
- What is the simplest way to solve the problem?
- What is an evolution of quantum light being created in the nonlinear process?

OBJECT OF INTEREST

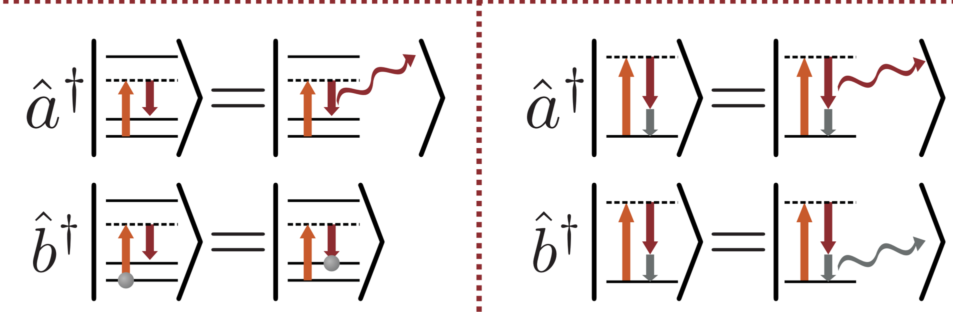
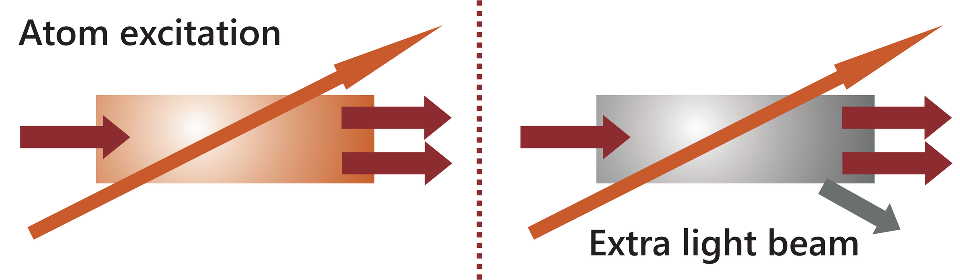


A) Optical Parametric Amplifier (OPA), commonly used as a source of non-classic light, generated in the spontaneous parametric down-conversion (SPDC).

B) Hot Rubidium vapours, a serious candidate for quantum memories, utilizing the process of the Raman scattering.

RAMAN SCATTERING VS. DOWN CONVERSION

$$\frac{\partial \hat{a}}{\partial t} = \frac{\hat{b}^\dagger}{L_{NL}} \qquad \frac{\partial \hat{b}}{\partial t} = \frac{\hat{a}^\dagger}{L_{NL}}$$

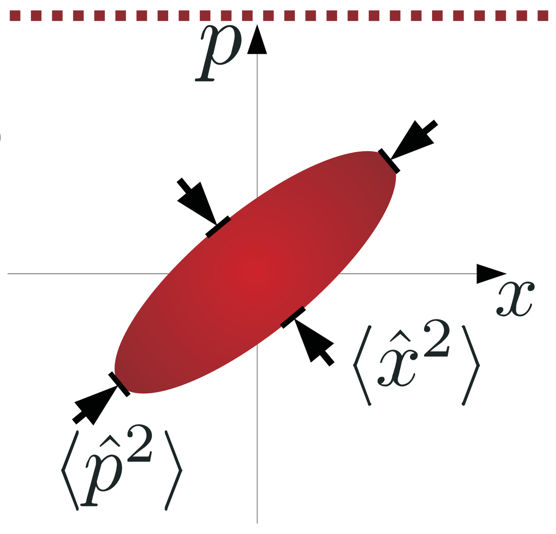
	RAMAN	NONDEGENERATE SPDC
Field operators: different meaning of $\hat{b}^\dagger$		
Signal beam amplification, idler as:	Atom excitation 	Extra light beam
Origin of losses	Loss of photons	Atomic depolarization

SQUEEZED STATES

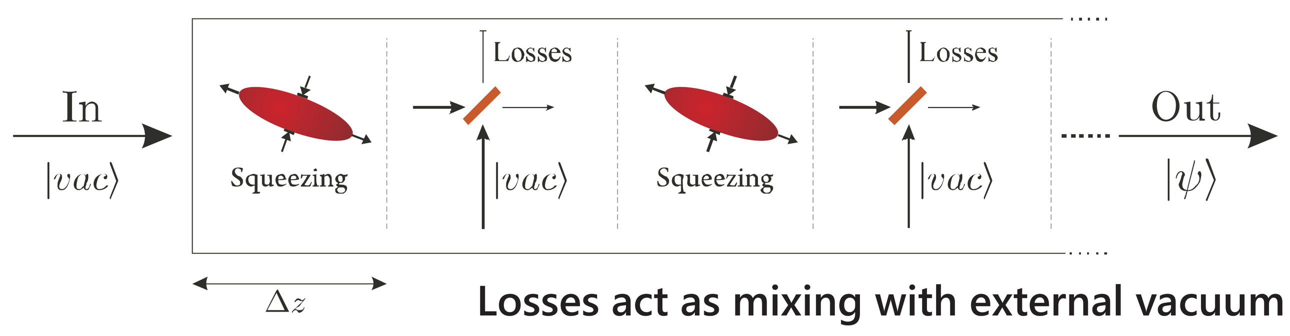
Field quadratures

$$\hat{E} = \hat{x}\cos\omega t + \hat{p}\sin\omega t$$

$$\hat{x} = \frac{\hat{a}^\dagger + \hat{a}}{\sqrt{2}} \qquad \hat{p} = \frac{i(\hat{a}^\dagger - \hat{a})}{\sqrt{2}}$$



Representation of the single mode squeezed state in the phase space.



Losses act as mixing with external vacuum modes. Tracking evolution of all modes becomes very difficult.

SINGLE MODE SPDC WITHOUT LOSSES

Analysis of $\hat{a}$ propagation

$$\frac{\partial \hat{a}}{\partial z} = \frac{\hat{a}^\dagger}{L_{NL}} \qquad L_{NL} \propto 1/P_0$$

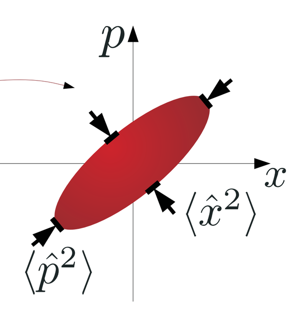
Single mode solution

$$\hat{a}_{out} = \hat{a}_{in}\cosh\zeta + \hat{a}_{in}^\dagger \sinh\zeta$$

Squeezing

$$\zeta = L/L_{NL}$$

$$\hat{x}_{out} = e^{-\zeta}\hat{x}_{in} \qquad \hat{p}_{out} = e^{\zeta}\hat{p}_{in}$$



Four length scales:

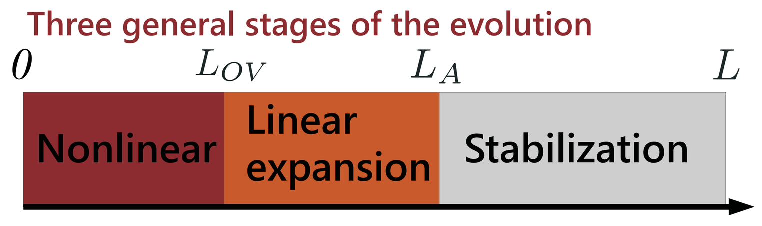
$L_{NL} \propto 1/P_0$	Nonlinear
$L_{OV} = \tau_P/\Delta\beta_1$	Overlap
$L_D = \tau_P^2/\beta_2$	Dispersive
L_A	Attenuation

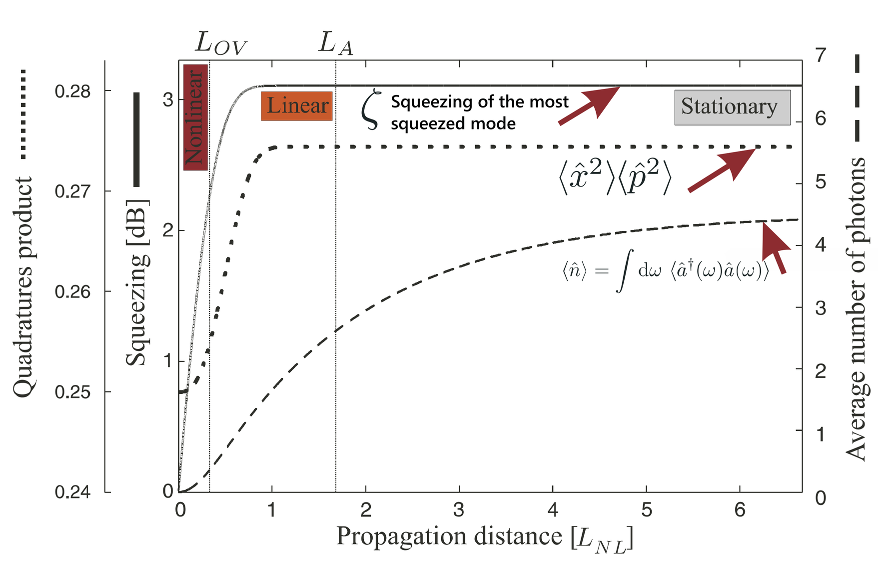
MULTIMODE DESCRIPTION

Approximations and assumptions:
- 1D model, degenerate model of OPA
- Undepleted pump.
- Losses affect only SPDC light.
- Numerical results and qualitative understunding

MULTIMODE MODE SOLUTION

Three general stages of the evolution





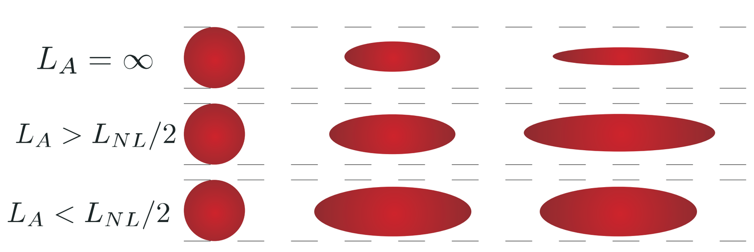
¡ANSWERS!

Nonclassical character of SPDC states still manifests itself in squeezing present even after severe attenuation!

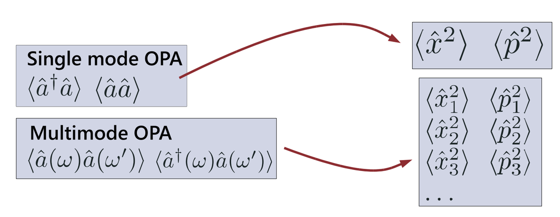
ONE MODE SOLUTION

Applicable when $L_A < L_{OV},\ L_D$

$$\langle \hat{x}^2\rangle = \frac{1}{2} + \frac{L_A}{2L_A \pm L_{NL}}\left(e^{-(L_A^{-1} \pm 2L_{NL}^{-1})L} - 1\right)$$



FIRST ORDER CORRELATION FUNCTIONS



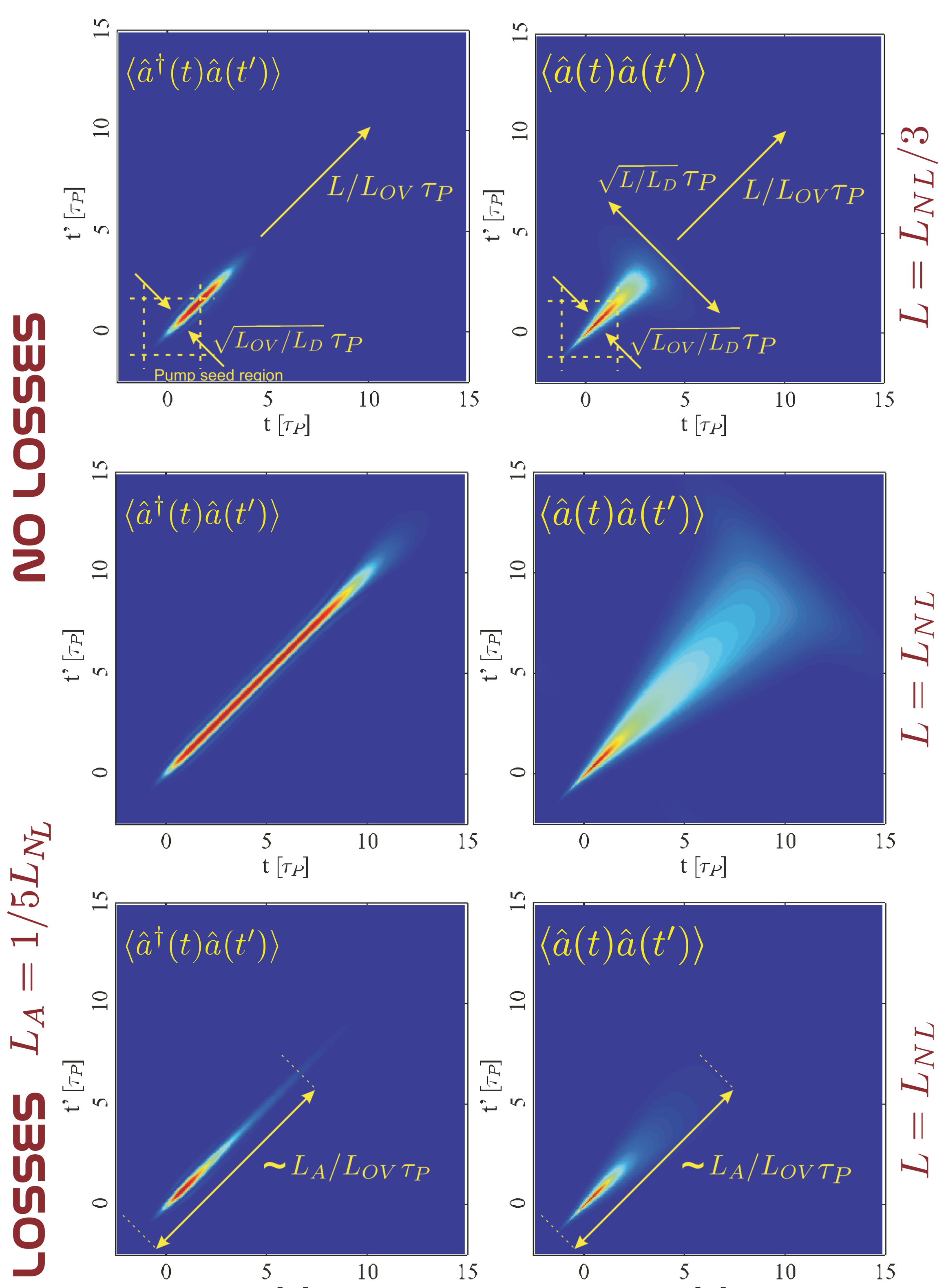
Equation of the evolution of the correlation functions

$$\frac{\partial\langle\hat{a}^\dagger\hat{a}\rangle}{\partial z} = \frac{2}{L_{NL}}\mathrm{Re}\langle\hat{a}\hat{a}\rangle - \frac{\langle\hat{a}^\dagger\hat{a}\rangle}{L_A}$$

$$\frac{\partial\langle\hat{a}\hat{a}\rangle}{\partial z} = \frac{2}{L_{NL}}\langle\hat{a}^\dagger\hat{a}\rangle + \frac{1}{L_{NL}} - \frac{\langle\hat{a}\hat{a}\rangle}{L_A}$$

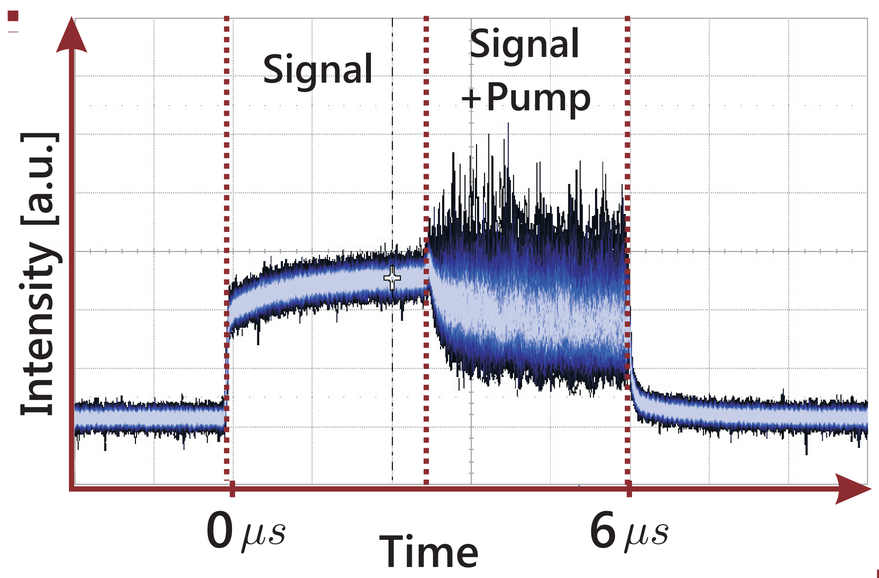
- They fully characterize gaussian states (SPDC quantum state remains gaussian even in the presence of losses).
- Their propagation equations can be easily formulated even in the presence of losses!

$L_{OV} = L_{NL}/10 \qquad L_D = 3L_{NL}$



Numerical solutions for the propagation of the correlation functions.

- Stimulated Raman Scattering.
- Simple quantum memories.
- Generation of single photons. And afterwards...
- ... read our results in journals:)!



Raman gain and attenuation. Experimental result in Rb87 vapour.

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REFERENCE

R. Chrapkiewicz, and W. Wasilewski, "Multimode spontaneous parametric down-conversion in a lossy medium", Journal of Modern Optics 57, 345-355 (2010).