Control of Spatial Instabilities with Intracavity Photonic Crystals

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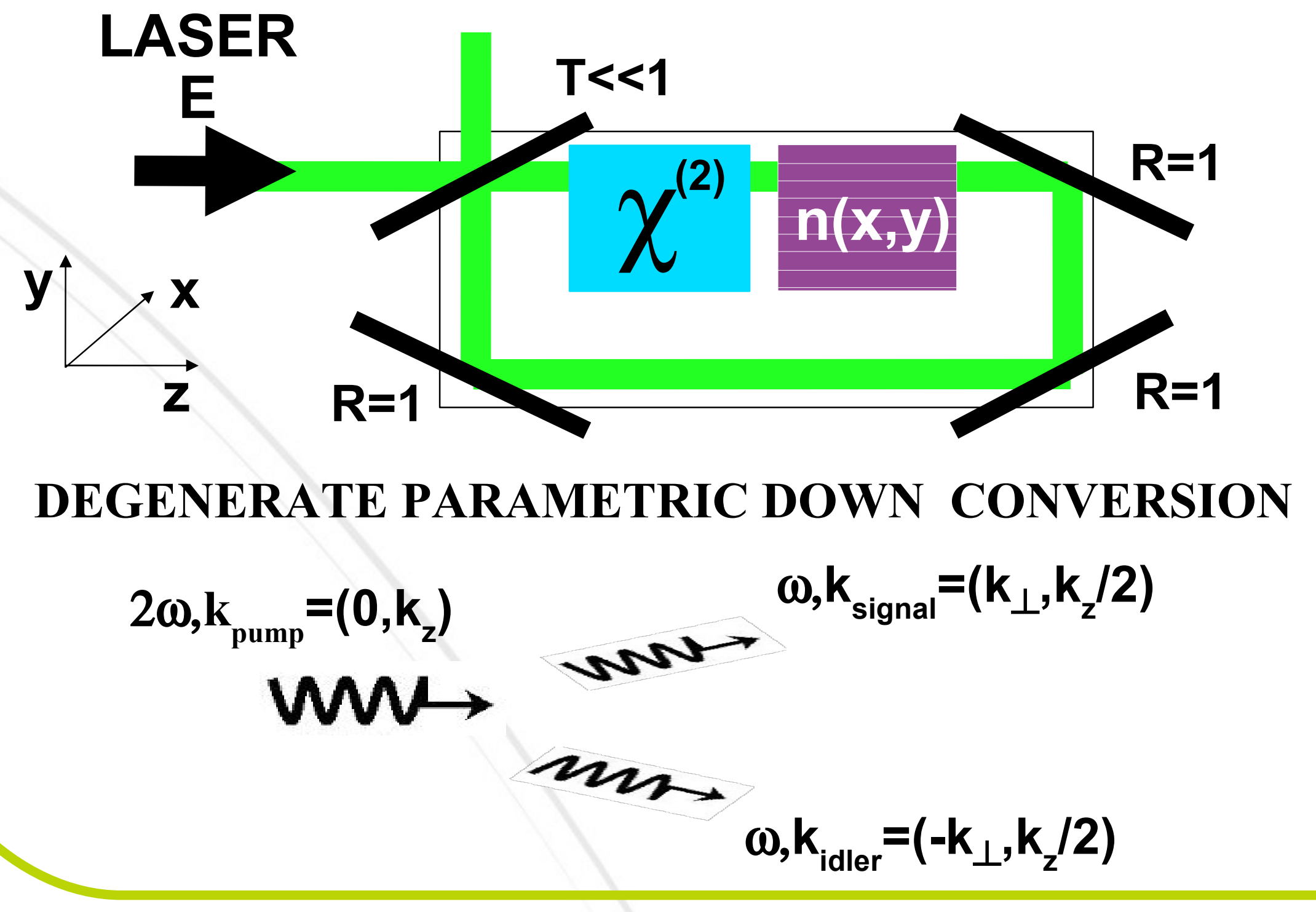
Abstract

Previous analyses of Kerr cavities have shown the possibility to inhibit the phenomenon of pattern formation using photonic crystals [1] as the instability threshold moves to larger values of the pump. This theoretical prediction has recently been confirmed in two independent experiments [2],[3]. In this work we extend the study to photonic crystals in type I degenerate optical parametric oscillators (PCOPO) showing novel effects. As a matter of fact, due to the presence of a field together with its harmonic, we show how photonic crystals act not only inhibiting but also stimulating spatial instabilities. PCOPO's are then devices with parametric thresholds tunable with the amplitude and/or periodicity of the photonic crystal. The efficiency of the process is also studied.

Model Description

Type I degenerate OPO with Intracavity Photonic Crystal



DEGENERATE PARAMETRIC DOWN CONVERSION

Spatial Instabilities in OPOs

NON-LINEARITY
LOSSES
DIFFRACTION
NEGATIVE Δ_1

PATTERN FORMATION
IN THE TRANSVERSE PROFILE
ABOVE THRESHOLD
AT k_c

Langevin equations in the Q representation

pump (ordinary polarization):

$$\partial_t \alpha_0(\vec{x},t) = -\left[(1+i(\Delta_0 + I_0 \sin k_p x) - i\nabla^2\right]\alpha_0(\vec{x},t) + E - \frac{1}{2}\alpha_1^2(\vec{x},t) + \sqrt{\frac{2}{a}\frac{g}{\gamma}}\xi_0(\vec{x},t)$$

signal (extraordinary polarization):

$$\partial_t \alpha_1(\vec{x},t) = -\left[(1+i(\Delta_1 + I_1 \sin k_p x) - 2i\nabla^2\right]\alpha_1(\vec{x},t) + \alpha_0(\vec{x},t)\alpha_1^*(\vec{x},t) + \sqrt{\frac{2}{a}\frac{g}{\gamma}}\xi_1(\vec{x},t)$$

LOSSES

DETUNING

PHOTONIC CRYSTAL

DIFFRACTION

MULTIPLICATIVE WHITE NOISE

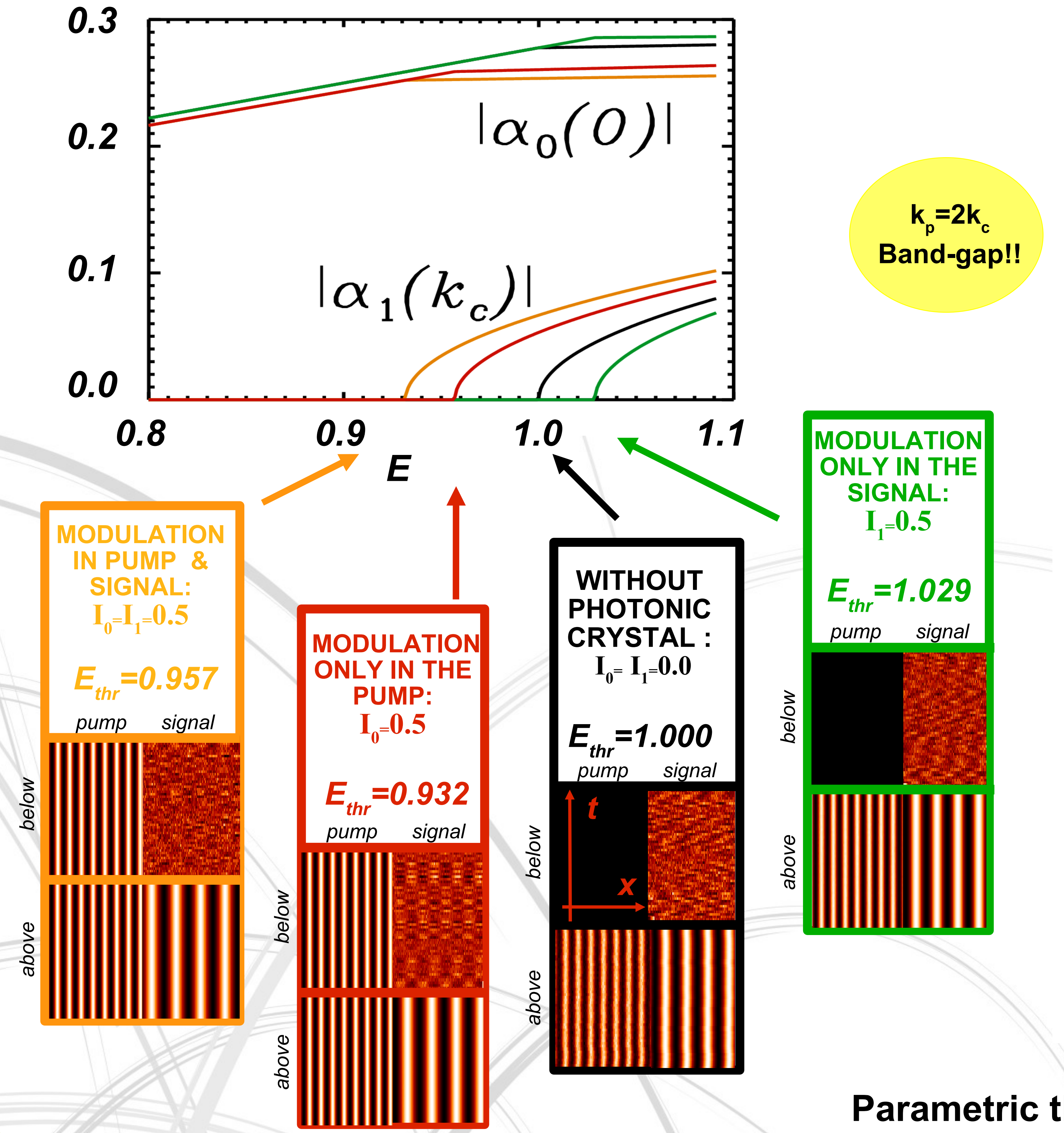
MULTIMODE & NON-LINEAR

$$\hat{H}_{int} \propto \int d\vec{x}^2 \left(\hat{A}_0(\vec{x},t)\hat{A}_1^{\dagger 2}(\vec{x},t) - \hat{A}_0^\dagger(\vec{x},t)\hat{A}_1^2(\vec{x},t)\right)$$

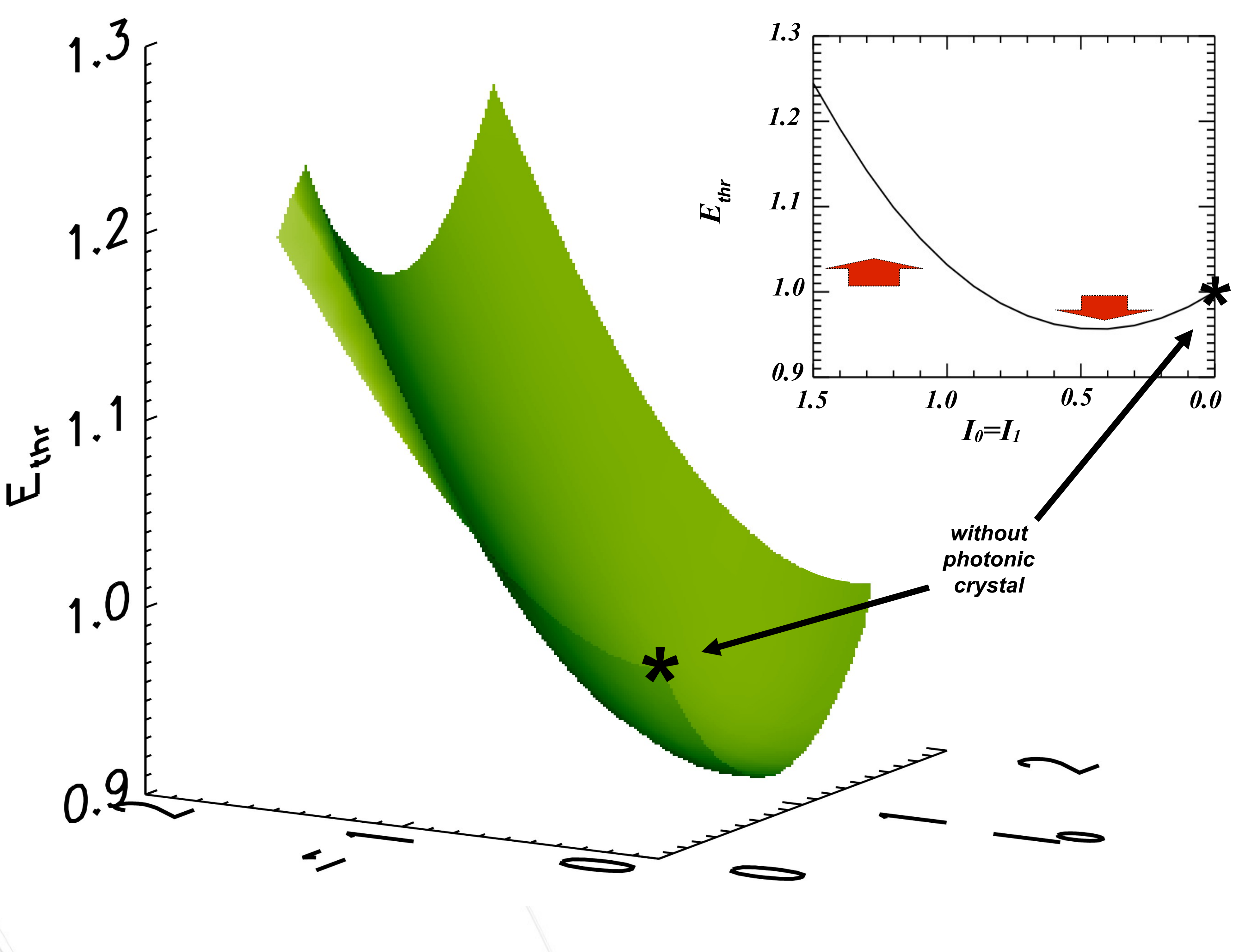
TWO IMPORTANT SPATIAL SCALES → k_c and k_p

Parametric and Modulation Instability Threshold Control

Down conversion efficiency



PHOTONIC CRYSTALS can either <u>STIMULATE</u> or <u>INHIBIT</u> the pattern



Parametric threshold increased or lowered ↔ spontaneous pattern inhibited or stimulated

Quantum fluctuations control (in progress)

- In PCOPOs the spontaneous emission can be inhibited or raised.
- There is reduction of quadratures noise with respect to the case of OPOs without photonic crystal.
- Connection: quantum noise suppression vs. translational symmetry.

Conclusions

- Photonic crystals in a non-linear cavity allow to tune the parametric threshold.
- Spatial instabilities can be either inhibited or stimulated depending on the configuration of the PCOPO. Ass a consequence also the efficiency can be tuned.
- The pattern is phase locked due to the spatial symmetry breaking introduced by the photonic crystal.

References

[1] a) D. Gomila, R. Zambrini and G-L. Oppo, "Photonic Band-Gap Inhibition of Modulational Instabilities", Phys.Rev. Lett. 92, 253904 (2004); b) D. Gomila and G-L. Oppo, "Coupled-mode theory for photonic band-gap inhibition of spatial instabilities", Phys.Rev. E 72, 016614 (2005)

[2] B. Terhalle, N. Radwell, P. Rose, C. Denz and T. Ackemann, "Control of broad-area vertical-cavity surface emitting laser emission by optically induced photonic crystals", Appl. Phys. Lett. 93, 151114 (2008)

[3] N. Marsal, D. Wolfersberger, M. Sciamanna, G. Montemezzani and D.N. Neshev, "Experimental control of pattern formation by photonic lattices", Opt. Lett. 33, 2509-2511 (2008)

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